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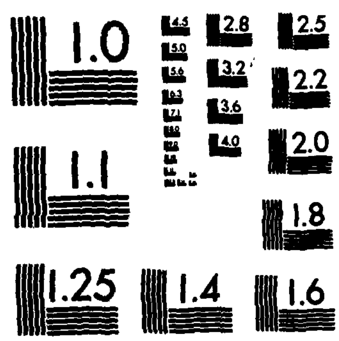
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THE WEATHERING OF PLASTICS
MATERIALS IN THE TROPICS

7 Evaluation of the Weathering Behaviour of a Variety of Glass Reinforced Polyester and Epoxy Resin Systems

Report by

Procurement Executive, Ministry of Defence/British
Plastics Federation Joint Working Party on the
Ageing and Weathering of Polymers and Composites

1982

Issued by

Procurement Executive, Ministry of Defence
Propellants, Explosives and Rocket Motor Establishment
Waltham Abbey
Essex

UNLIMITED

PROCUREMENT EXECUTIVE, MINISTRY OF DEFENCE

THE WEATHERING OF PLASTIC MATERIALS IN THE TROPICS

7 EVALUATION OF THE WEATHERING BEHAVIOUR OF A VARIETY OF GLASS REINFORCED POLYESTER AND EPOXY RESIN SYSTEMS

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SUMMARY

This report contains the results of a trial conducted in Australia and the United Kingdom to evaluate the weathering of glass fibre reinforced laminates. The laminates represented a number of commercially available resin/glass combinations including polyester and epoxy resins, woven roving, chopped strand mat and satin weave glass reinforcement.

Some difficulty was experienced in interpreting the experimental results but positive trends are established for the long term, eight year behaviour. Some differentiation between resin systems has been possible.

CONTENTS

1 INTRODUCTION

The objective of this trial was to determine the effects of outdoor temperate and tropical exposure on glass fibre laminates of known composition and method of manufacture. These were representative of commercially available systems.

The main variables were resin, (polyester and epoxy), curing system and nature of glass reinforcement (chopped strand mat, woven roving and satin weave glass cloth).

All the laminates were prepared by one fabricator. They were exposed at the hot dry and hot wet sites of the Joint Tropical Trials and Research Establishment (JTTRE), Australia. (This was originally called the Joint Tropical Research Unit). The temperate exposure was conducted at Turner Brothers Asbestos Co Ltd, Rochdale.

Withdrawals of laminates were made at two, four and six or eight year periods and the effect of weathering was monitored by assessment of appearance, change in weight and dimensions, flexural and tensile properties, acetone soluble matter, glass content and electrical properties.

2 MATERIALS

The materials used are shown below and in more detail in Appendix 1. These materials were supplied by the British Plastics Federation.

2.1 Polyester Resins

a. Low reactivity orthophthalic polyester resin)
b. High reactivity orthophthalic polyester resin)
cured using methyl ethyl ketone peroxide (MEKP) and a cobalt accelerator.

These two systems were hand laid-up, cold set and hot post cured, 48 hours at 100°C.

c. Low reactivity orthophthalic polyester resin)
d. High reactivity orthophthalic polyester resin)
cured using a benzoyl peroxide

These two systems were hot cured, 1 hour at 120°C.

2.2 Epoxy Resins

a. Standard epoxy resin cured using methyl nadic anhydride.

b. Standard epoxy resin cured using diamino diphenyl methane.

These two systems were hot press moulded followed by a post cure of 48 hours at 100°C.

c. Standard epoxy resin (modified with n - Butyl glycidyl ether) cured using triethylene tetramine.

This system was hand laid-up, cold cured and hot post cured for 48 hours at 100°C.

2.3 Glass Fibre Reinforcement

a. "A" glass chopped strand mat

b. "E" glass chopped strand mat

c. Woven roving

d. Satin weave glass fabric

All glass reinforcement had a silane finish, A172 for the polyester resins and A1100 for the epoxy resins.

2.4 Laminates

The various resin/glass combinations are shown below, Table 1. Laminates of these combinations were prepared under standard conditions by one fabricator, the Atomic Weapons Research Establishment, using hand lay up techniques plus press moulding to size under given curing conditions.

The laminates were nominally 3 mm thick and were 305 mm square for the chopped strand mat and satin weave reinforcement and 305 mm x 380 mm for the woven roving reinforcement.

3 EXPOSURE

The following exposure sites were used:

(i) Hot Wet Cleared, Innisfail, (JTTRE)

(ii) Hot Dry, Cloncurry, (JTTRE)

(iii) Temperate, Rochdale (Turner Bros Asbestos Co Ltd)

TABLE 1

Types of Glass Reinforced Polyester and Epoxy Resin Laminates

Material No	Resin/Hardener System	Reinforcement
1	Polyester HR/Benzoyl Peroxide	S2/225/E satin weave cloth
2	Polyester HR/Benzoyl Peroxide	E glass woven roving, 20 oz/sq yd
3	Polyester HR/Benzoyl Peroxide	A glass CSM, Deeglass A 105
4	Polyester HR/Benzoyl Peroxide	E glass CSM, Fibreglass FGE 4000
5	Polyester HR/MEKP/Cobalt	S2/225/E satin weave cloth
6	Polyester HR/MEKP/Cobalt	E glass woven roving, 20 oz/sq yd
7	Polyester HR/MEKP/Cobalt	A glass CSM, Deeglass A 106
8	Polyester HR/MEKP/Cobalt	E glass CSM, Fibreglass FGE 2000
9	Polyester LR/Benzoyl Peroxide	S2/225/E satin weave cloth
10	Polyester LR/Benzoyl Peroxide	E glass woven roving, 20 oz/sq yd
11	Polyester LR/Benzoyl Peroxide	A glass CSM, Deeglass A 105
12	Polyester LR/Benzoyl Peroxide	E glass CSM, Fibreglass FGE 4000
13	Polyester LR/MEKP/Cobalt	S2/225/E satin weave cloth
14	Polyester LR/MEKP/Cobalt	E glass woven roving, 20 oz/sq yd
15	Polyester LR/MEKP/Cobalt	A glass CSM, Deeglass A 106
16	Polyester LR/MEKP/Cobalt	E glass CSM, Fibreglass FGE 2000
17	Epoxide formula 1	S2/225/E satin weave cloth
18	Epoxide formula 2	S2/225/E satin weave cloth
19	Epoxide formula 3	S2/225/E satin weave cloth

The laminates were mounted in racks at 45° to the horizontal facing the equator.

Withdrawals were made after two, four and eight years exposure for the chopped strand mat and satin weave reinforced laminates and after two, four and six years for the woven roving reinforcement.

4 TEST METHODS

4.1 Visual Assessment

An assessment of change of colour, dirt, erosion, microbiological growth and opacity was made.

4.2 Weight and Dimensional Changes

Changes in weight and dimensions were recorded on uncut laminates after each withdrawal.

4.3 Mechanical Properties

a. Flexural modulus and strength

b. Tensile modulus and strength

The test specimens were cut from the exposed laminates. All specimens were conditioned at 65 ± 5% RH and $20^{\circ} \pm 2^{\circ}C$ for 28-30 days. Flexural properties were also determined on specimens which had been conditioned by immersion in water at $20^{\circ} \pm 2^{\circ}C$ for the same period. All properties were determined at room temperature.

4.4 Other Properties

a. Acetone soluble matter

An acetone soluble matter test was carried out on the polyester resin systems only in an attempt to monitor any change in the state of cure of the laminates with time of exposure.

b. Glass content

The glass content of laminates was determined to monitor any changes reflecting resin loss and also to enable valid mechanical property comparisons to be made.

c. Electrical properties

Loss tangent, permittivity, surface and volume resistivity were determined.

Details of the test methods are shown in Appendix 2.

5 RESULTS OTHER THAN MECHANICAL PROPERTIES

5.1 Visual Assessment

Specimens were assessed after each withdrawal and the results are shown in Appendix 3. An interesting observation from the colour change data is that all the satin weave cloth reinforced systems initially fade but eventually darken.

Microbiological growth is, not unexpectedly, limited to the specimens exposed under hot/wet conditions. This made visual assessment of the laminates very difficult. Light transmission could not be assessed and erosion, although apparent, could not be accurately assessed.

At the hot/dry site, colour change, dirt retention and erosion were rated as severe for all specimens. Fibre prominence was excessive for all but one of the chopped strand mat reinforced systems and the gauge marks on these specimens disappeared.

5.2 Weight Changes

The weight change results are shown in Appendix 4. The most apparent weight changes are the consistent losses, of the order of 1 to 3%, at the hot/dry site. These weight losses vary only slightly with the resin system and reinforcement.

The weight increases observed at the temperate site are in the main independent of the resin system but appear to be influenced by the type of reinforcement used. Higher weight increases were consistently observed for the composite reinforced with chopped strand mat which had a higher resin content.

The weight changes obtained from the hot/wet site are unusual in that they indicate that this environment has apparently the least effect on the exposed panels. However as the panels were not cleaned during exposure and as previously noted were coated with a fungal growth it is considered that some screening effect has occurred to minimise the weight changes and mask a true result.

5.3 Dimensional Changes

The disappearance of the gauge marks on the choppeu strand mat reinforced systems due to erosion during the course of this trial made it impossible to determine length and breadth changes. In addition several other dimensional change results are not available. Thus a detailed analysis is not possible and the results are shown in Appendix 4.

The available results shows that there is little significant difference between the four polyester resin systems. Within each polyester resin system the various glass reinforcements appear to make little difference although the dimensional change for one of the woven roving reinforced systems is the highest recorded.

The dimensional changes for the three epoxy systems are very similar to each other and to those from the polyester systems. Overall, the dimensional changes show small increases, less than 0.5%.

5.4 Electrical Results

The results of measurements of permittivity, loss tangent, surface and volume resistivity showed no clear trends. The results are shown in Appendix 5.

5.5 Acetone Soluble Matter

The results of this test are presented together with the individual mechanical test results for tensile property in Appendix 6 for completeness. No attempt has been made to interpret the results.

5.6 Glass Content

The results of the determination of glass content are also shown in Appendix 6. The variation in glass content results does not warrant using them to normalize the mechanical property results.

6 PRESENTATION AND INTERPRETATION OF MECHANICAL PROPERTY RESULTS

All the mechanical property data is presented in tabular form in Appendices 6 and 7. Appendix 6 contains the results after the 2,4,6 and 8 years exposure periods and Appendix 7 shows the 8 year results together with computed property losses. Results from exposure at the hot/wet site have been presented graphically in figures 1 to 7 in Appendix 8.

6.1 Polyester Resin Laminates Reinforced with Chopped Strand Mat or Satin Weave Fabric

The most detailed analysis was carried out on the results obtained after the full eight years exposure. Some laminates exhibited apparently anomalous results after the intermediate 2 and 4 year exposure periods, and it is not known whether these are significant or real results as further investigation uncovered significant differences in properties between replicate laminates. It is only if the eight year results are considered that a clear pattern emerges which relates degradation to site, resin reactivity and type of cure.

Almost without exception, the greatest degradation of properties takes place at the hot/wet site. In this report, therefore, greater emphasis has been focussed on the results obtained from material exposed at the hot/wet site for the 8 year period. In all cases property figures are the mean of six determinations and the property loss expressed as a percentage of the initial control laminate. In the case of flexural strength the initial value used was the mean property of 16 replicate laminates of each type determined at the time of manufacture for quality control purposes.

6.2 Polyester Resin Laminates Reinforced with Woven Rovings

Due to a misinterpretation of the test data derived after the 4 year exposure period all the roving laminates from all sites were withdrawn after 6 years exposure instead of 8. In the event this was unnecessary. Such data as there is from this part of the trial indicates that the results from these laminates were a great deal more erratic than the results from laminates made with the other reinforcements. No attempt has been made to analyse this data further.

6.3 Epoxy Resin Laminates

The same presentation has been used for the laminates made with epoxy resin as was used for those made from polyester resin.

7 RESULTS AND DISCUSSION OF MECHANICAL PROPERTIES OF LAMINATES MADE WITH POLYESTER RESINS

7.1 Flexural Strength

In general, flexural strength measured in the wet conditioned state was found to be less than that after dry conditioning. This was true irrespective of reinforcement, resin reactivity, type of cure, site and time of exposure. With very few exceptions the percentage loss of flexural strength measured after 8 years exposure at all of the sites was least for laminates made with a MEK peroxide catalysed system. This is irrespective of whether the laminates had been made with low or high reactivity resin.

Comparing like reinforcements with like, in all cases laminates made with low reactivity resin, whatever the curing system, had higher initial flexural strengths than their counterparts made with high reactivity resin. Apart from some results from laminates made with MEK peroxide cured high reactivity resin, this superiority was maintained for all laminates after exposure on all sites and up to and including the 8 year exposure period. The effect was particularly marked for the laminates made with benzoyl peroxide cured resins. To illustrate this point the wet conditioned flexural strengths of laminates made with benzoyl peroxide cured high and low reactivity resins after exposure for 8 years at the hot/wet site are shown in Appendix 8 Figure 1. Similar plots (not presented) of the results from identical laminates after 8 years exposure at the temperate and hot/dry sites lead to the same conclusion. If the results from the MEK peroxide cured laminates are plotted in the same way the picture is less clear-cut but the trend is certainly the same.

The above observations and trends remain the same when the results are expressed in terms of percent loss of flexural strength based on the initial mean strength. Some of this data is shown in Appendix 8 Figure 2. So far all the observations have referred to material tested in the wet conditioned state but an analysis of the results of tests on the same laminates in the dry conditioned state confirms these observations and reveals the same trends.

The results from laminates exposed for 8 years at the hot/dry site, with very few exceptions, are bracketed by those obtained from laminates exposed for the same time at the hot/wet and temperate sites, although they are in general closer to those obtained from the latter site. Considering all laminate types after 8 years at the hot/wet site, the flexural strength losses ranged from 28-61% when tested in the dry conditioned state and from 32-69% after wet conditioning.

7.2 Flexural Modulus

The picture presented by the modulus results is similar to that for the flexural strength results although the evidence is not quite so clear cut, there are for example rather more apparently anomalous results at the 8 year exposure period. For all cases but one, "E" glass CSM/benzoyl peroxide cured low reactivity resin, the greatest modulus losses were recorded for laminates exposed for 8 years at the hot/wet site. Modulus losses for all laminates ranged from 17 to 66 percent of the initial figure for dry conditioned material.

There is little difference between the initial modulus of composites made with benzoyl peroxide or MEK peroxide cured high or low reactivity resin. The only exception to this finding are the results for composites made with "E" glass CSM and benzoyl peroxide and MEK peroxide cured high reactivity resin which were significantly higher than those given by the corresponding laminates made with low reactivity resin. No explanation can be found for this. In both these cases the composites made with high reactivity resin lost a greater percentage of their initial modulus over the 8 year exposure period than their counterparts made with low reactivity resin. Indeed a comparison of absolute figures shows that the MEK peroxide and benzoyl peroxide cured low reactivity resin types are as good as, and in most cases superior, to the high reactivity types after this exposure period. This confirms a similar finding from the flexural strength results. If the loss of modulus after exposure for 8 years at the hot/wet site is expressed as a percentage of the initial, dry conditioned, figure, then the picture is less clear. On this basis, only the results for laminates made with "E" glass CSM and MEK peroxide or benzoyl peroxide cured low reactivity resin remain clearly superior; the results for laminates made with "A" glass CSM or satin weave cloth, while still confirming the trend, are closer to those given by similar laminates made with high reactivity resin.

7.3 Tensile Strength

An analysis of the data reveals that in all cases the tensile strength of the materials falls after an 8 year exposure period and the greatest losses occur at the hot/wet site. For the intermediate 2 and 4 year exposure periods the trend is for strength to decrease but, as in the case of flexural strength, there are a number of anomalous results.

In the case of laminates made with "A" glass CSM and "E" glass CSM and MEK peroxide cured high reactivity resin, the initial strength figures are lower than expected. They should be very similar to the MEK peroxide cured low reactivity types and they cannot be reconciled with strength figures obtained after 2, 4 and 8 year exposures. Thus the mean tensile strength figures after 2 years hot/dry exposure seemed reasonable figures to choose as a base.

Analysis of the tensile strength results confirms the trends found for the flexural strength and modulus ie the laminates made with benzoyl peroxide cured high reactivity resin suffer the greatest percentage loss of strength and that the lowest losses, almost without exception, were sustained by laminates made with low reactivity resin. There is also a very clear indication that MEK peroxide curing is beneficial whether used for high or low reactivity resins. These points are illustrated well by a comparison of the data plotted in Appendix 8 Figures 2 and 4 in which, with only slight differences, the same order of merit is given in respect of resin reactivity and type of cure.

A comparison of the absolute figures confirms the finding that in all cases the results from laminates made with low reactivity resin are superior to those made with high reactivity resin and that, in general, MEK peroxide curing is beneficial.

With few exceptions the tensile strength figures after 8 years hot/dry exposure are bracketed by those obtained from laminates after 8 years exposure at the temperate and hot/wet sites. Considering all laminate types, the tensile strength losses after 8 years at the hot/wet site range between 20 and 60 percent of the initial laboratory value.

7.4 Tensile Modulus

Of the four mechanical properties tested in this trial, tensile modulus is the only one where the loss of property, if any, is small and in some cases where a small gain is recorded.

The change in tensile modulus ranges from + 12 percent to - 22 percent. Laminates made with satin weave cloth gave the most consistent results with a range of modulus change of + 2 percent to - 10 percent.

The greatest loss in tensile modulus for laminates made with each of the three reinforcements is associated with those laminates made with high reactivity resin and in two of these cases the resin was also benzoyl peroxide cured (Appendix 8 Figure 5). This confirms similar findings derived from the other mechanical property tests after 8 years hot/wet exposure.

7.5 Discussion

Much of the material used in this trial was variable with coefficients of variation for some mechanical property values ranging up to 20 percent. Thus, when relating property degradation to exposure site, resin reactivity, reinforcement and type of cure it can only be in terms of trends. Nevertheless these trends in many cases are unmistakable and the conclusions drawn from the results of different property tests are consistent to such an extent that some clear patterns emerge.

A study of Appendix 8 Figures 1-4 shows the inferior performance of laminates made with high reactivity resin when compared to laminates made with low reactivity resin. Almost as clear cut is the extremely strong indication that curing with MEK peroxide, whether used for high or low reactivity resin, is beneficial if laminates are to resist the effects of hot/wet exposure.

These findings appear to run contrary to the expectations that the fibre/resin bond would be higher and the resin more highly cross-linked in those laminates made with benzoyl peroxide cured high reactivity resin as compared to those made with MEK peroxide cured low reactivity resin and that the former laminates would therefore be more environmentally resistant.

It is known that the state of the fibre/resin bond is more critical in the determination of flexural properties than in the determination of tensile properties, and that it is susceptible to degradation. This is supported by the data from this trial where the losses in flexural strength are in general 10-15% greater than the losses in tensile strength.

There is some indication that laminates made with "A" glass CSM suffered greater losses in property after 8 years hot/wet exposure than similar laminates made with "E" glass CSM demonstrating the susceptibility of "A" glass to moisture attack. Further indication of this may be seen from the tensile modulus data presented in Appendix 8 Figure 5.

With very few exceptions the loss of property results from laminates exposed at the hot/dry site are bracketed by those obtained from laminates exposed at the hot/wet and temperate sites after 8 years exposure. On economic and other grounds therefore the need to expose so much material at hot/dry sites can be questioned. This is particularly pertinent in the case of materials which are not greatly affected by solar radiation. For future trials involving glass reinforced polyester resins, a reduction in the amount of material exposed at hot/dry sites should be considered together with the possibility of omitting this exposure environment altogether. Exposure for 8 years at the hot/dry site and the temperate site resulted in property losses as high as 54 percent and 50 percent respectively although in general the bulk of the property losses recorded for these two sites were less than this.

With the exception of tensile modulus all the mechanical property losses, after 8 years hot/wet exposure, were substantial and covered the range 17-69 percent of initial mean values. Such large losses are serious and must, inevitably, have an adverse effect on the size of design and safety factors.

8 RESULTS AND DISCUSSION OF MECHANICAL PROPERTIES OF LAMINATES MADE WITH EPOXY RESINS

8.1 Flexural and Tensile Properties

Unlike the results from the polyester laminates the mechanical test results from the very limited range of epoxy laminates used in this trial do not show any clear trends (Appendix 9 Figures 6-7). However a number of general observations can be made.

On the whole the highest property losses are recorded after 8 years exposure at the hot/wet site (Appendix 8 Figure 6) but many of the results from the temperate and hot/dry sites were of the same order - particularly for flexural strength and modulus. Losses of 3-35 percent and 19-44 percent were recorded for flexural strength and modulus respectively.

Tensile strength and modulus were little affected although the one exception to this observation was the 33 percent loss of tensile strength o, laminates made with epoxy resin cured with triethylene-tetramine (TETA). It may be significant that this was the only cold cured epoxy resin/hardener system used. The tensile strength and modulus data is plotted in Appendix 8 Figure 7.

8.2 Discussion

There are two main features of interest in the results from laminates made with epoxy resin. Firstly there is the high loss of flexural modulus. This loss is as great if not greater than for flexural strength and indicates severe fibre/resin bond damage or damage to the reinforcement.

From the limited amount of data available it would appear that the best all round resistance to the hot/wet environment is given by the laminates made with methyl nadic anhydride cured epoxy resin.

Although there is a trend for the results from the hot/dry site to be bracketed by those from the temperate and hot/wet site it is not so marked a feature of these results as it was for those obtained from laminates made with polyester resin.

9 CONCLUSIONS

The variation of property between replicate laminates was too large to allow comparison after short times of exposure. The following conclusions are therefore based on the comparison of mechanical properties retained after eight years exposure with original values before exposure. Despite the variability of the data resulting in a qualitative assessment only, the trends and losses of property recorded are significant and must be taken into account in quoting property data for design purposes.

(a) The hot/wet environment at Innisfail proves to be the most aggresive condition for all the glass fibre/resin systems under test.

(b) The methyl ethyl ketone peroxide cured low reactivity polyester resin system was superior to the other polyester resin systems tested.

(c) The epoxy resin systems with property losses of up to 40% appear to weather better than polyester resin systems with property losses of up to 70%.

(d) The methyl nadic anhydride cured system showed the least loss of property of the epoxy resin systems under trial.

A detailed list of all conclusions drawn from the mechanical testing in this trial is included for reference in Appendix 9.

10 RECOMMENDATIONS

(a) In further trials of this nature considerable emphasis should be put on reducing the variability between replicate laminates and being fully aware of its extent before exposure commences.

(b) Results obtained from interim withdrawals should be monitored closely.

(c) Consideration should be given in trials of glass reinforced plastics to limiting exposure to the temperate and hot/wet sites.

11 ACKNOWLEDGEMENTS

The assistance of the staff at the following establishments is gratefully acknowledged; the British Plastics Federation, the Atomic Weapons Research Establishment, the Propellants, Explosives and Rocket Motor Establishment (formerly the Explosives Research and Development Establishment), the Materials Quality Assurance Directorate, the Joint Tropical Trials and Research Establishment formerly the Joint Tropical Research Unit). Particular thanks are due to Mr P McMullen of the Royal Aircraft Establishment for his efforts in interpreting the mass of data acquired during this trial.

APPENDIX 1

MATERIALS

A1. 1 HIGH REACTIVITY POLYESTER RESIN

This resin was specially manufactured to the following specification by BIP Chemicals Ltd on behalf of the polyester resin manufacturer members of the Federation.

Formulation

(1)	Maleic anhydride	-	2 mol.
(2)	Phthalic anhydride	-	1 mol.
(3)	*Propylene glycol	-	3 mol.
(4)	Hydroquinone	-	0.008% on blended resin
(5)	Styrene	-	to give 65/35 alkyd: styrene

*Plus up to 10% excess depending on characteristics of plant used.

Final Product Specification

Viscosity	-	0.8 Pa.s
Acid value (Alkyd)	-	28-35 mgm KOH per gram
Gel time at 25^{o}C	-	17-33 min
Stability at 55^{o}C	-	at least 5 days

A1. 2 LOW REACTIVITY POLYESTER RESIN

This resin was specially manufactured to the following specification by BIP Chemicals Ltd, on behalf of the polyester resin manufacturer members of the Federation.

Formulation

(1)	Maleic anhydride	-	1 mol.
(2)	Phthalic anhydride	-	2 mol.
(3)	*Propylene glycol	-	3 mol.
(4)	Hydroquinone	-	0.008% on blended resin
(5)	Styrene	-	to give 65/35 alkyd: styrene

*Plus up to 10% excess depending on characteristics of plant used.

Final Product Specification

Viscosity	-	0.6 Pa.s
Acid value (alkyd)	-	28-35 mgm KOH per gram
Gel time at $25^{o}C$	-	27-33 min
Stability at $55^{o}C$	-	at least 5 days

A1. 3 EPOXY RESINS

These resin systems were specially manufactured to the following formulae by the Shell Chemical Co Ltd, on behalf of the epoxy resin manufacturer members of the Federation.

Standard Liquid Resin

A resin based on Bisphenol A and epichlorhydrin of viscosity 10-15 Pa.s at $25^{o}C$ and with weight per epoxy of 175-210.

Formula 1		parts by weight
	Standard liquid resin	100
	Methyl nadic anhydride	90
	Benzyl dimethyl amine	1
Formula 2		
	Standard liquid resin	100
	Diamino diphenyl methane	27
Formula 3		
	Standard liquid resin	100
	n-Butyl glycidyl ether	15
	Triethylene tetramine	15

A1. 4 GLASS REINFORCEMENTS

The yarn for all E glass reinforcements was supplied by Fibreglass Ltd.

All reinforcements for polyester resins were finished with Silane A 172, those for epoxy resins with Silane A 1100.

1 S2/225/E Cloth

E glass satin weave cloth supplied finished as above by Marglass Ltd.

2 <u>E Glass Woven Roving</u>

20 oz/sq yd supplied by Fothergill & Harvey Ltd.

3 <u>A Glass Chopped Strand Mat</u>

(a) <u>For Hot Press Moulding</u>

Deeglas A 105 supplied by Deeglas Fibres Ltd.

(b) <u>For Hand Lay Up</u>

Deeglas A 106 supplied by Deeglas Fibres Ltd.

4 <u>E Glass Chopped Strand Mat</u>

(a) <u>For Hot Press Moulding</u>

Fibreglass FGE 4000 supplied by Fibreglass Ltd.

(b) <u>For Hand Lay Up</u>

Fibreglass FGE 2000 supplied by Fibreglass Ltd.

TEST METHODS

A2. 1 PREPARATION OF TEST SPECIMENS

The cutting plans allowed for Quality Control Specimens to be checked by the manufacturer and also allowed for the two narrow margins in contact with the exposure racks to be discarded. This had the additional advantage of ensuring that no test specimen was taken wholly from an exposed cut edge.

Test specimens were cut as required using a suitable saw. The edges of the specimens had a smooth finish.

All cutting, machining and finishing operations were slow enough to avoid undue heating, delamination or physical damage of the specimens. Particular care was taken in the cutting of the weathered specimens.

A2. 2 TENSILE TEST

The test specimen was a rectangular bar 230 mm long and 25 mm wide with a thickness of the sheet under test.

Due to testing machine limitations the early tests were conducted by loading the specimen in a stepwise manner and the extension of a 50 mm gauge length was recorded at each step. Each increment of load was approximately one tenth of the load recorded at failure.

The final withdrawal tests were conducted on an Instron testing machine using a cross-head rate of 1 mm/min.

The tensile modulus, calculated from the initial straight line portion of the load/extension graph, and the tensile strength were determined.

A2. 3 FLEXURAL TEST

The test specimen was a rectangular bar 25 mm wide for woven roving laminates and 12.5 mm wide for the remainder. They were 100 mm long and the thickness of the sheet under test.

The testing machine applied a bending load by means of a loading nose parallel to and exactly mid-way between two parallel supporting blocks placed 50.8 mm apart. The contact edges of the supporting blocks and loading nose had a radius of 1.6 mm (1/16").

The test was conducted at 12.5 mm/min ($\frac{1}{2}$"/min) and the flexural strength and modulus calculated in the usual way.

A2. 4 ACETONE SOLUBLE MATTER AND GLASS CONTENT

The acetone soluble matter test was carried out only on the polyester laminates and the same sample of material was then used for glass content determination. A 2 gram sample of each laminate was placed in a "cold" soxhlet extractor and extracted with acetone (AR grade) for four hours.

To determine the glass content the thimble was placed in a muffle furnace at 650^{o}C for three hours.

A2. 5 ELECTRICAL PROPERTIES

(a) Loss Tangent and Permittivity

This was determined at 23^{o}C at a frequency of 1 M Hz according to BS 2067 (1953) using tinfoil/petroleum jelly electrodes on the fabric based laminates only.

(b) Surface and Volume Resistivity

This was determined according to BS 2782 Method 202A and 203A (1965).

Visual Appearance

Material	Site	Colour Years				Dirt Years				Erosion Years				Microbiological Years				Opacity Years			
		2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
	Temp	-1	-2	-	+3	0	1	-	2	0	1	-	2	0	0	-	NA	1	2	-	NA
1	H Wet	-2	-4	-	+4	3	4	-	4	2	4	-	NA	2	4	-	4	3	4	-	NA
	H Dry	-4	-3	-	+4	0	2	-	4	2	3	-	4	0	0	-	NA	3	3	-	NA
	Temp	+1	+2	+2	-	0	2	2	-	1	2	2	-	0	0	0	-	1	2	3	-
2	H Wet	+3	-4	+4	-	3	3	4	-	2	4	4	-	1	4	4	-	2	3/4	NA	-
	H Dry	+4	+3	+3	-	0	3	1	-	2	3	4	-	0	0	0	-	2	3	2	-
	Temp	+2	+3	-	+3	0	0	-	2	1	2	-	2	0	0	-	0	0	1	-	NA
3	H Wet	+3	-4	-	+4	3	4	-	4	3	4	-	NA	3	4	-	4	2	4	-	NA
	H Dry	+4	+4	-	+4	0	3	-	4	3	4	-	4	0	0	-	NA	1	1	-	NA
	Temp	+2	+2	-	+3	0	0	-	2	0	1	-	2	0	0	-	0	0	1	-	NA
4	H Wet	+3	+3	-	+4	3	4	-	4	3	4	-	NA	3	4	-	4	2	4	-	NA
	H Dry	+4	+4	-	+4	0	3	-	4	4	4	-	4	0	0	-	NA	1	1	-	NA
	Temp	+1	-1	-	+3	0	1	-	2	0	1	-	2	0	0	-	0	3	4	-	NA
5	H Wet	-3	-3	-	+4	3	3	-	4	3	4	-	NA	1	4	-	4	4	4	-	NA
	H Dry	-4	-3	-	+4	0	2	-	4	1	3	-	4	0	0	-	NA	2	3	-	NA
	Temp	+1	+2	+3	-	0	0	1	-	1	3	3	-	0	0	0	-	0	1	1	-
6	H Wet	+3	+4	+4	-	2	3	4	-	2	4	4	-	0	4	4	-	1	0/2	NA	-
	H Dry	+4	+4	+3	-	0	2	1	-	1	3	4	-	0	0	0	-	2	0	2	-
	Temp	+2	+2	-	+2	0	1	-	2	0	1	-	2	0	0	-	0	1	1	-	NA
7	H Wet	+2	+4	-	+4	3	3	-	44	3	4	-	NA	2	4	-	4	2	4	-	NA
	H Dry	+3	+4	-	+4	0	4	-	4	4	4	-	4	0	0	-	NA	2	1	-	NA
	Temp	+1	+2	-	+3	0	1	-	2	1	2	-	1	0	0	-	0	0	0	-	NA
8	H Wet	+2	+4	-	+4	3	3	-	4	2	4	-	NA	2	4	-	4	1	1/2	-	NA
	H Dry	+2	+4	-	+4	0	3	-	4	4	4	-	4	0	0	-	NA	2	0	-	NA
	Temp	+1	+2	-	+3	0	1	-	2	1	1	-	2	0	0	-	0	1	2	-	NA
9	H Wet	-3	-4	-	+4	2	3	-	4	3	4	-	NA	1	4	-	4	3	3/4	-	NA
	H Dry	-3	+3	-	+4	0	2	-	4	1	3	-	4	0	0	-	NA	2	2/3	-	NA
	Temp	+1	+2	+3	-	0	1	2	-	0	1	2	-	0	0	0	-	1	2	2	-
10	H Wet	+3	+3	+4	-	2	3	4	-	3	4	4	-	1	4	4	-	0	3/4	NA	-
	H Dry	+4	+4	+3	-	0	3	1	-	2	3	4	-	0	0	0	-	4	3	1	-
	Temp	+2	+3	-	+2	0	2	-	2	1	3	-	2	0	3	-	0	1	3	-	NA
11	H Wet	+3	+4	-	+4	2	4	-	4	3	4	-	NA	3	4	-	4	3	2/4	-	NA
	H Dry	+4	+4	-	+4	1	2	-	4	4	4	-	4	0	0	-	NA	2	1	-	NA
	Temp	+1	+3	-	+3	0	1	-	2	1	2	-	2	0	0	-	NA	0	1	-	NA
12	H Wet	+3	-4	-	+4	2	3	-	4	3	4	-	NA	3	4	-	4	2	2/4	-	NA
	H Dry	+4	+3	-	+4	1	3	-	4	4	4	-	4	0	0	-	NA	2	0/1	-	NA
	Temp	+1	2	-	+2	0	1	-	3	1	2	-	2	0	0	-	0	1	3	-	NA
13	H Wet	-2	-4	-	+4	2	3	-	4	3	4	-	NA	1	4	-	4	2	3/4	-	NA
	H Dry	-3	-3	-	+4	0	2	-	4	3	3	-	4	0	0	-	NA	3	3	-	NA

Assessment:

0 = No change

4 = Severe change

NA = Result not available

Colour: + = darkened, - = faded

APPENDIX 3

Visual Appearance (Cont'd)

Material	Site	Colour Years 2	4	6	8	Dirt Years 2	4	6	8	Erosion Years 2	4	6	8	Microbiological Years 2	4	6	8	Opacity Years 2	4	6	8
14	Temp	+2	+4	+4	-	1	2	2	-	1	3	3	-	0	1	0	-	1	2	3	-
	H Wet	+3	-4	+4	-	2	4	4	-	2	4	4	-	1	4	4	-	1	2/3	NA	-
	H Dry	+3	+4	+3	-	2	3	1	-	1	3	4	-	0	0	0	-	3	0	0	-
15	Temp	+1	+3	-	+3	0	2	-	2	1	2	-	1	0	0	-	0	1	1	-	NA
	H Wet	+2	-4	-	+4	3	2	-	4	3	4	-	NA	2	4	-	4	3	4	-	NA
	H Dry	+3	+4	-	+4	1	3	-	4	3	4	-	4	0	0	-	NA	1	1	-	NA
16	Temp	0	+1	-	+2	0	1	-	2	0	1	-	2	0	0	-	0	0	0	-	NA
	H Wet	+2	-4	-	+4	2	4	-	4	2	4	-	NA	0	4	-	4	1	2	-	NA
	H Dry	+3	+4	-	+4	1	3	-	4	4	4	-	4	0	0	-	NA	2	0	-	NA
17	Temp	-1	-2	-	+3	0	0	-	2	0	1	-	1	0	0	-	0	1	3	-	NA
	H Wet	-3	-4	-	+4	1	4	-	4	4	4	-	NA	1	4	-	4	4	3/4	-	NA
	H Dry	-3	-4	-	+4	1	2	-	4	3	4	-	4	0	0	-	NA	2	1	-	NA
18	Temp	-2	-3	-	+3	0	1	-	2	1	2	-	1	0	0	-	0	1	2	-	NA
	H Wet	-3	-4	-	+4	1	3	-	4	4	4	-	NA	0	4	-	4	3	4	-	NA
	H Dry	-3	-4	-	+4	0	2	-	4	3	4	-	4	0	0	-	NA	1	2/3	-	NA
19	Temp	-1	-3	-	+2	0	1	-	2	1	2	-	1	0	0	-	0	1	2	-	NA
	H Wet	-3	-4	-	+4	2	4	-	4	3	4	-	NA	1	4	-	4	3	3/4	-	NA
	H Dry	-3	-4	-	+4	0	2	-	4	3	4	-	4	0	0	-	NA	2	2/3	-	NA

Assessment:

0 = No change

4 = Severe change

NA = Result not available

Colour: + = darkened, - = faded

Weight and Dimensional Changes

Material	Site	Weight change %				Dimensional change %							
		24 months	48 months	72 months	96 months	24 months		48 months		72 months		96 months	
						L	B	L	B	L	B	L	B
	Control UK	-	-	-	+0.1	-	-	-	-	-	-	0	+0.1
	Tropical	-	+0.3	-	+0.1	-	-	-	-	-	-	+0.3	+0.1
1	Temperate	+0.2	0	-	+0.4	0	0	0	0	-	-	+0.1	+0.1
	Hot Wet	-0.1	-0.5	-	-1.3	0	0	-0.3	0	-	-	+0.1	+0.3
	Hot Dry	-0.5	-1.0	-	-2.0	0	0	0	0	-	-	+0.3	+0.1
	Control UK	-	-	+0.1	-	-	-	-	-	+0.3	+0.3	-	-
	Tropical	-	+0.3	+0.1	-	-	-	-	-	-	-	-	-
2	Temperate	+0.6	-0.2	+0.3	-	0	0	0	0	-	-	-	-
	Hot Wet	+0.2	-0.5	-0.7	-	0	0	-0.1	+0.1	NA	NA	-	-
	Hot Dry	-0.4	-1.0	-1.8	-	0	0	+0.1	-0.1	-0.4	-0.1	-	-
	Control UK	-	-	-	+0.2	-	-	-	-	-	-	+0.1	0
	Tropical	-	+0.4	-	+0.3	-	-	-	-	-	-	+0.2	+0.1
3	Temperate	+0.5	+0.2	-	+1.1	0	0	0	0	-	-	+0.2	+0.1
	Hot Wet	+0.3	-0.1	-	-1.1	0	0	-0.1	+0.1	-	-	+0.2	+0.1
	Hot Dry	-0.4	-0.8	-	-2.9	0	0	0	NA	-	-	NA	NA
	Control UK	-	-	-	+0.1	-	-	-	-	-	-	+0.2	+0.2
	Tropical	-	+0.3	-	+0.2	-	-	-	-	-	-	+0.2	+0.4
4	Temperate	+0.2	+0.5	-	+1.4	0	0	-	-	-	-	+0.2	+0.3
	Hot Wet	-0.1	+0.3	-	-0.3	0	0	+0.1	+0.1	-	-	+0.2	+0.2
	Hot Dry	-0.6	-0.9	-	-3.0	0	0	NA	NA	-	-	NA	NA
	Control UK	-	-	-	0	-	-	-	-	-	-	+0.1	+0.1
	Tropical	-	+0.1	-	+0.1	-	-	-	-	-	-	+0.2	+0.2
5	Temperate	+0.2	-0.2	-	0.4	0	0	0	0	-	-	+0.1	+0.1
	Hot Wet	-0.2	0	-	0	0	0	0	+0.3	-	-	+0.2	+0.5
	Hot Dry	-0.4	-0.9	-	-1.9	0	0	+0.1	-0.1	-	-	+0.2	0
	Control UK	-	-	+0.1	-	-	-	-	-	+0.1	+0.2	-	-
	Tropical	-	+0.2	+0.1	-	-	-	-	-	-	-	-	-
6	Temperate	+0.4	-0.2	0	-	0	0	0	0	NA	NA	-	-
	Hot Wet	+0.2	+0.1	+0.5	-	0	0	+0.3	-0.1	NA	NA	-	-
	Hot Dry	-0.4	-0.8	-1.5	-	-0.1	0	+0.1	-0.1	+0.1	+0.7	-	-
	Control UK	-	-	-	+0.1	-	-	-	-	-	-	+0.1	0
	Tropical	-	+0.3	-	+0.2	-	-	-	-	-	-	+0.1	+0.1
7	Temperate	+0.2	0	-	+1.2	0	0	0	0	-	-	+0.1	+0.1
	Hot Wet	+0.4	-0.3	-	-0.5	+0.1	+0.1	+0.1	+0.1	-	-	NA	NA
	Hot Dry	-0.7	-1.0	-	-2.6	0	0	NA	NA	-	-	NA	NA
	Control UK	-	-	-	+0.1	-	-	-	-	-	-	+0.2	+0.2
	Tropical	-	+0.3	-	+0.2	-	-	-	-	-	-	+0.3	+0.2
8	Temperate	0	0	-	+1.3	0	0	0	0	-	-	+0.2	+0.2
	Hot Wet	+0.3	+0.2	-	+0.4	0	-0.1	+0.1	0	-	-	+0.2	+0.1
	Hot Dry	-0.5	-0.8	-	-2.6	0	0	NA	NA	-	-	NA	NA
	Control UK	-	+0.2	-	0	-	-	-	-	-	-	+0.1	+0.1
	Tropical	-	+0.2	-	+0.1	-	-	-	-	-	-	+0.1	+0.1
9	Temperate	+0.4	-0.2	-	+0.4	0	0	0	0	-	-	+0.1	+0.1
	Hot Wet	-0.1	-0.2	-	+0.4	0	0	0	+0.1	-	-	+0.2	+0.3
	Hot Dry	-0.4	-0.8	-	-1.6	0	0	-0.1	-0.1	-	-	+0.2	+0.2
	Control UK	-	+0.2	-0.3	-	-	-	-	-	+0.1	+0.3	-	-
	Tropical	-	-0.2	-0.3	-	-	-	-	-	-	-	-	-
10	Temperate	+0.2	-0.2	0	-	0	0	-0.1	0	NA	NA	-	-
	Hot Wet	+0.3	-0.8	-1.6	-	0	0	0	0	NA	NA	-	-
	Hot Dry	-0.6	-0.9	-1.9	-	0	-0.1	0	-0.3	+0.5	+0.4	-	-

APPENDIX 4

Weight and Dimensional Changes (Contd)

Material	Site	Weight change %				Dimensional change %							
		24 months	48 months	72 months	96 months	24 months		48 months		72 months		96 months	
						L	B	L	B	L	B	L	B
	Control UK	-	+0.2	-	+0.1	-	-	-	-	-	-	0	0
	Tropical	-	+0.3	-	+0.1	-	-	-	-	-	-	+0.1	+0.1
11	Temperate	0	-0.5	-	+1.0	0	0	0	-0.1	-	-	+0.1	+0.2
	Hot Wet	-0.3	0	-	-0.1	0	-0.1	-0.1	-0.1	-	-	+0.1	+0.2
	Hot Dry	-0.5	NA	-	-2.1	0	0	NA	NA	-	-	NA	NA
	Control UK	-	+0.2	-	0	-	-	-	-	-	-	+0.1	0
	Tropical	-	+0.3	-	+0.1	-	-	-	-	-	-	+0.1	+0.1
12	Temperate	+0.5	-0.2	-	+1.1	0	0	0	0	-	-	+0.2	+0.1
	Hot Wet	0	0	-	-0.4	0	0	-0.1	0	-	-	+0.3	+0.1
	Hot Dry	-0.5	-0.9	-	-2.4	+0.1	0	NA	NA	-	-	NA	NA
	Control UK	-	+0.2	-	+0.1	-	-	-	-	-	-	+0.1	+0.1
	Tropical	-	+0.2	-	+0.1	-	-	-	-	-	-	+0.1	+0.1
13	Temperate	+0.2	-0.4	-	+0.4	0	0	0	0	-	-	+0.1	+0.1
	Hot Wet	0	-0.3	-	+0.3	0	0	+0.1	-0.1	-	-	+0.5	+0.2
	Hot Dry	-0.4	-0.6	-	-1.6	0	-0.1	NA	NA	-	-	+0.2	+0.2
	Control UK	-	0	+0.2	-	-	-	-	-	+0.2	+0.1	-	-
	Tropical	-	+0.1	+0.2	-	-	-	-	-	-	-	-	-
14	Temperate	+0.2	-0.4	0	-	0	0	0	0	NA	NA	-	-
	Hot Wet	+0.1	-1.8	-0.1	-	+0.1	0	0	-0.1	NA	NA	-	-
	Hot Dry	-0.3	-0.8	-1.3	-	0	0	-0.1	0	0	-0.3	-	-
	Control UK	-	+0.2	-	+0.1	-	-	-	-	-	-	+0.1	+0.2
	Tropical	-	+0.2	-	+0.1	-	-	-	-	-	-	+0.2	+0.2
15	Temperate	-0.5	-0.4	-	+1.4	0	0	0	0	-	-	+0.2	+0.2
	Hot Wet	+0.2	-0.9	-	-1.0	0	+0.1	0	-0.1	-	-	+0.2	+0.4
	Hot Dry	-0.5	-0.8	-	-2.4	0	0	NA	NA	-	-	NA	NA
	Control UK	-	+0.2	-	+0.1	-	-	-	-	-	-	+0.2	+0.2
	Tropical	-	+0.2	-	+0.1	-	-	-	-	-	-	+0.2	+0.2
16	Temperate	0	-0.4	-	+1.0	0	0	0	0	-	-	+0.2	+0.2
	Hot Wet	+0.2	+0.1	-	+0.2	+0.1	0	+0.1	+0.3	-	-	+0.1	+0.2
	Hot Dry	-0.3	-0.9	-	-2.2	0	-0.1	+0.4	0	-	-	NA	NA
	Control UK	-	+0.2	-	+0.3	-	-	-	-	-	-	+0.2	+0.1
	Tropical	-	+0.3	-	+0.3	-	-	-	-	-	-	+0.3	+0.1
17	Temperate	0	-1.0	-	+0.4	0	0	0	0	-	-	+0.3	+0.3
	Hot Wet	-0.5	-0.8	-	-0.9	+0.1	0	+0.1	+0.1	-	-	+0.3	+0.3
	Hot Dry	-0.4	-0.9	-	-2.6	0	0	0	-0.1	-	-	+0.4	+0.1
	Control UK	-	+0.2	-	+0.2	-	-	-	-	-	-	+0.2	+0.2
	Tropical	-	+0.3	-	+0.3	-	-	-	-	-	-	+0.2	+0.2
18	Temperate	-0.2	-1.4	-	+0.5	0	0	0	0	-	-	+0.2	+0.3
	Hot Wet	-1.0	-1.5	-	-0.8	0	0	-0.1	-0.3	-	-	+0.3	+0.1
	Hot Dry	-0.6	-1.1	-	-2.1	0	0	0	0	-	-	+0.1	+0.3
	Control UK	-	+0.2	-	+0.2	-	-	-	-	-	-	+0.1	+0.1
	Tropical	-	+0.5	-	+0.4	-	-	-	-	-	-	+0.2	0
19	Temperate	+0.2	-0.4	-	+0.4	0	0	0	0	-	-	+0.2	+0.2
	Hot Wet	-0.4	-0.4	-	+0.3	+0.1	0	+0.1	+0.1	-	-	+0.4	+0.1
	Hot Dry	-0.6	-1.2	-	-2.7	-0.1	0	+0.1	+0.1	-	-	-0.2	+0.3

L: Length
B: Breadth

Electrical Results

Material	Test	Controls 0	Controls 96 (temp)	Controls 96 (trop)	Temperate 24	Temperate 48	Temperate 96	Hot-Wet 24	Hot-Wet 48	Hot-Wet 96	Hot-Dry 24	Hot-Dry 48	Hot-Dry 96
1	K	4.16	4.4		4.52		4.12			4.11			2.85
	Tan δ	0.0115	0.0148		0.0235		0.0178			0.020			0.0172
	S Res ohm x 10^{12}	122	63.6	23.4		0.326	0.014	5.94		1.30	21.5		0.268
	V Res ohm x 10^{12}	760	571	810		50.15	1.68	92.0		1.78	297.5		6.18
3	K		4.76	4.05			3.60			3.20			3.35
	Tan δ		0.0208	0.0224			0.0226			0.0233			0.0184
	S Res ohm x 10^{12}		0.0062	1.96		26.4	1.17	0.275		0.405	2.48		0.091
	V Res ohm x 10^{12}		0.0649	0.0676		14.75	10.09	2.795		2.87	3.13		3.03
4	K		3.68	3.72			3.35			3.03			3.46
	Tan δ		0.0184	0.013			0.0219			0.0221			0.0166
	S Res ohm x 10^{12}		56.0	56.0		0.088	0.064	19.10		1.12	42.0		7.23
	V Res ohm x 10^{12}		758	1028		7.43	0.348	159.0		2.53	517.5		608.00
5	K	4.17	4.69	4.69	4.32		4.41			3.94			4.38
	Tan δ	0.0131	0.0144	0.0144	0.0201		0.013			0.016			0.0136
	S Res ohm x 10^{12}	148	106	153		0.628	0.013	11.17		5.63	39.6		2.36
	V Res ohm x 10^{12}	1575	2280	2000		530.7	1.09	289.5		0.547	477.00		3.65
7	K		3.87	4.18			3.67			2.97			3.72
	Tan δ		0.0246	0.0217			0.0221			0.0238			0.0264
	S Res ohm x 10^{12}		0.06	0.96		7.06	3.42	2.08		0.039	4.88		1.05
	V Res ohm x 10^{12}		0.695	16.3		-	15.1	23.0		9.88	43.8		10.9
8	K		3.79	3.92			3.17			3.1			3.50
	Tan δ		0.0199	0.194			0.0156			0.0235			0.0185
	S Res ohm x 10^{12}		510	270		0.935	0.206	27.85		0.54	167.0		758
	V Res ohm x 10^{12}		14000	2520		747	34.8	597.5		17.9	982.5		240
9	K	3.99	4.29	4.28	4.55		3.40			3.40			4.28
	Tan δ	0.0096	0.010	0.0102	0.0252		0.0209			0.0109			0.0092
	S Res ohm x 10^{12}	240	79.1	85.5		1.91	0.0073	13.75		0.44	21.35		3.38
	V Res ohm x 10^{12}	1012	2170	514.6		96.6	0.643	151.5		4.71	339.5		241

K: permittivity
Tan δ: loss tangent
S res: surface resistivity
V res: volume resistivity

Electrical Results (cont'd)

Material	Test	Controls 0	Controls 96 (temp)	Controls 96 (trop)	Temperate 24	Temperate 48	Temperate 96	Hot-Wet 24	Hot-Wet 48	Hot-Wet 96	Hot-Dry 24	Hot-Dry 48	Hot-Dry 96
11	K		3.86	3.98			3.11			2.86			3.64
	Tan δ		0.0284	0.0422			0.0137			0.0172			0.0307
	S Res ohm x 10^{12}		0.0037	0.0317		3.81	2.86	0.572		0.547	5.415		0.182
	V ohm x 10^{12}		0.0157	0.578		17.5	7.45	21.55		2.26	4.325		6.04
12	K		3.54	3.62			3.59			2.90			3.64
	Tan δ		0.0126	0.0120			0.0144			0.0136			0.0314
	S Res ohm x 10^{12}		223.9	4571		0.164	0.024	14.20		1.08	57.75		0.18
	V Res ohm x 10^{12}		1675	6266		38.15	1.39	210.5		13.18	716.5		6.04
13	K	4.14	4.58	4.32	4.76		4.29			3.82			4.17
	Tan δ	0.0123	0.0100	0.0099	0.0255		0.012			0.013			0.0096
	S Res ohm x 10^{12}	82.8	93.2	2285		0.464	0.026	17.2		0.60	15.95		0.86
	V Res ohm x 10^{12}	686	241	1690		40.5	0.95	178		10.9	294		544
15	K		3.70	3.74			3.31			3.19			3.39
	Tan δ		0.0184	0.019			0.0148			0.0174			0.0187
	S Res ohm x 10^{12}		2.76	0.19		12.6	16.4	4.47		0.885	9.10		0.076
	V Res ohm x 10^{12}		7.31	2.83		79.35	78.6	70.55		19.2	15.45		4.91
16	K		3.56	3.72			3.56			3.26			3.76
	Tan δ		0.0145	0.0126			0.0150			0.0169			0.0138
	S Res ohm x 10^{12}		273	146		0.541	0.73	4.47		0.46	9.10		2.54
	V Res ohm x 10^{12}		5888	849		357.5	50.7	70.55		50.8	15.45		2000
17	K	4.42	4.52	4.40	4.44		4.32			4.26			3.545
	Tan δ	0.0164	0.0163	0.0149	0.0174		0.0156			0.0143			0.0162
	S Res ohm x 10^{12}		3.54	2.01		0.294	0.032	3.613		9.15	34.46		0.26
	V Res ohm x 10^{12}		98.9	1290		73.5	1.15	274		515	332		26.4
18	K	4.75	5.14	4.52	4.25		4.68			4.04			4.63
	Tan δ	0.0114	0.024	0.0242	0.0142		0.024			0.020			0.0205
	S Res ohm x 10^{12}		184	12.4		1.81	0.17	1.095		0.33	62.75		9.70
	V Res ohm x 10^{12}		676	7362		320	4.37	385.00		35.2	282.5		539
19	K	4.75	4.72	4.74	4.12		4.32			3.98			4.39
	Tan δ	0.0214	0.0244	0.0220	0.0121		0.0231			0.0213			0.0201
	S Res ohm x 10^{12}		61.4	1807		8.77	1.59	8.58		0.40	84.25		39.8
	V Res ohm x 10^{12}		78.5	2023		112	726	102.5		19.7	247.5		603.9

K: permittivity
Tan δ: Loss tangent
S res: Surface resistivity
V res: Volume resistivity

Electrical Results (Cont'd)

Material	Test	Controls			Temperate			Hot-Wet			Hot-Dry		
		0	72		24	48	72	24	48	72	24	48	72
2	K		4.18				4.21			4.33			4.35
	Tan δ		0.015				0.019			0.0188			0.0184
	S Res ohm x 10^{12}	344.6				0.845		12.15		0.55	25.8		0.13
	V Res ohm x 10^{12}	915				143.5		219		9.0	377.5		11.0
6	K		4.24				4.26			4.18			4.21
	Tan δ		0.015				0.017			0.0128			0.0174
	S Res ohm x 10^{12}				318.3	11.9		29.28		0.016	91.0		0.26
	V Res ohm x 10^{12}				1720	531.5		332.5		0.122	527.5		105
10	K		4.22				4.23			4.22			4.22
	Tan δ		0.011				0.012			0.012			0.011
	S Res ohm x 10^{12}	144				1.215		4.57			15.15		0.068
	V Res ohm x 10^{12}	414				30.6		74.0			306		0.13
14	K		4.24				4.18			4.38			4.22
	Tan δ		0.011				0.012			0.0196			0.012
	S Res ohm x 10^{12}	353				20.5		89.3		0.105	18.05		0.07
	V Res ohm x 10^{12}	892				482		315.5		0.90	202.5		12.5

K: Permittivity

Tan δ: Loss Tangent

S Res: Surface resistivity

V Res: Volume resistivity

TABLE 1

Mean Flexural Strength, after 2,4,6 and 8 Years Exposure of all Laminates made with Benzoyl Peroxide cured High Reactivity Polyester Resin

Site	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth		Woven Roving	
	Initial Flexural Strength	114		192		347		220	
	C of V	6.40		13.5		6.64		21.0	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
	Exposure (Years)								
Temp	2	92.8	104	134	176	250	319	251	305
	4	92.0	106	98.1	124	204	255	202	235
	8	73.2	83.8	106	130	175	217	254	252*
	8 Lab	96.2	115	169	242	325	392	204	278*
Hot Dry	2	97.6	108	158	178	177	317	292	337
	4	87.8	85	114	132	220	263	136	184
	8	80.3	97.9	93.7	134	164	214	114	156*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	81.4	114	91.5	114	246	272	252	285
	4	75.5	91	86.7	100	181	252	166	205
	8	54.6	64.7	59.9	74.4	118	163	227	187*
	8 Lab	100	114	141	181	333	389	-	-

TABLE 2

Mean Flexural Strength in MPa after 2,4,6 and 8 Years Exposure of all Laminates made with Methyl Ethyl Ketone Peroxide cured High Reactivity Polyester Resin

Site	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth.		Woven Roving	
	Initial Flexural Strength	134		195		365		212	
	C of V	8.10		9.54		5.76		16.6	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
	Exposure (Years)								
Temp	2	93.8	94.7	153	181	414	427	325	411
	4	101	92.5	174	151	345	381	291	360
	8	108	121	153	169	279	354	236	212*
	8 Lab	125	119	163	177	423	452	337	302*
Hot Dry	2	112	115	165	171	303	329	324	355
	4	104	104	155	150	352	351	247	288
	8	106	112	152	179	248	277	217	330*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	113	113	165	177	337	366	256	284
	4	107	101	164	167	260	346	258	367
	8	74.1	70.6	133	139	202	249	94.8	135*
	8 Lab	110	137	193	207	416	435	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after six years

APPENDIX 6

TABLE 3

Mean Flexural Strength in MPa after 2,4,6 and 8 Years Exposure of all Laminates made with Benzoyl Peroxide Cured Low Reactivity Polyester Resin

	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth		Woven Roving	
	Initial Flexural Strength	141		221		413		114	
	C of V	8.72		7.79		6.48		19.2	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)								
Temp	2	89.5	107	151	184	340	354	176	208
	4	95.5	118	166	195	292	355	133	199
	8	97.2	104	166	187	261	322	137	153*
	8 Lab	114	133	190	236	434	453	117	162*
Hot Dry	2	124	132	190	215	366	450	106	162
	4	117	111	134	169	271	349	117	193
	8	91.4	99.6	121	147	231	274	95.4	154*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	80.3	102	158	178	317	342	151	191
	4	111	116	154	181	286	387	123	168
	8	71.2	71.2	131	141	207	232	214	318*
	8 Lab	129	137	196	218	398	474	-	-

TABLE 4

Mean Flexural Strength in MPa after 2,4,6 and 8 Years Exposure of all Laminates made with Methyl Ethyl Ketone Peroxide Cured Low Reactivity Polyester Resin

	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth		Woven Roving	
	Initial Flexural Strength	149		208		369		248	
	C of V	12.4		8.61		12.3		25.1	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)								
Temp	2	96.0	114	157	164	329	395	232	293
	4	105	132	149	173	313	372	277	372
	8	111	124	146	171	268	324	248	223*
	8 Lab	108	127	154	171	420	473	298	253*
Hot Dry	2	112	117	187	158	326	395	269	329
	4	111	117	139	138	292	308	226	300
	8	107	124	164	169	251	280	231	302*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	99.8	128	179	191	342	363	253	319
	4	[illegible]	130	172	185	293	366	237	332
	8	81.4	87.9	136	136	225	262	135	[illegible]
	8 Lab	123	127	170	189	416	495	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after 6 years

TABLE 5

Mean Flexural Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Benzoyl Peroxide Cured High Reactivity Resin

Site	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth		Woven Roving	
	Initial Flexural Modulus	5.10	6.83	7.58	10.1	18.5	19.2	14.8	14.8
	C of V	8.62	11.3	17.0	5.62	1.47	4.46	7.88	2.68
	Conditions	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)								
Temp	2	6.07	7.58	7.24	8.27	15.4	19.3	13.8	15.4
	4	5.03	6.76	5.79	6.62	15.9	17.7	14.3	14.2
	8	4.76	4.83	5.45	5.93	12.1	12.3	10.3	8.14*
	8 Lab	5.17	6.41	7.03	8.48	15.6	16.3	10.8	9.93*
Hot Dry	2	4.90	6.76	6.27	8.76	15.0	15.4	8.83	13.8
	4	4.96	6.00	5.65	6.00	13.7	16.3	13.4	13.5
	8	4.69	5.10	4.62	5.45	12.8	13.3	9.58	9.51*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	5.45	6.41	4.48	5.58	14.1	18.1	10.8	12.0
	4	6.34	7.31	6.83	8.41	17.2	21.9	12.7	13.7
	8	3.24	3.59	3.38	3.86	11.1	11.7	10.5	9.58*
	8 Lab	5.17	5.58	5.79	6.14	16.1	15.0	-	-

TABLE 6

Mean Flexural Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Methyl Ethyl Ketone Peroxide Cured High Reactivity Resin

Site	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth		Woven Roving	
	Initial Flexural Modulus	5.52	7.58	7.45	9.93	21.1	21.4	14.2	15.7
	C of V	6.77	9.71	6.85	6.08	5.02	12.5	3.60	5.89
	Conditions	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)								
Temp	2	5.38	7.45	6.89	8.34	16.7	19.9	15.3	15.3
	4	5.65	6.34	7.10	7.72	16.5	18.2	14.1	14.6
	8	5.52	5.72	6.14	6.48	13.5	13.4	9.38	9.86*
	8 Lab	6.07	6.83	6.76	7.65	16.6	17.0	12.1	10.0*
Hot Dry	2	5.17	6.83	6.96	8.62	16.1	18.1	14.8	15.3
	4	5.58	6.00	7.03	7.52	17.8	18.5	11.7	10.5
	8	4.96	5.38	6.14	6.96	13.1	13.2	9.65	13.0*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	6.00	6.48	7.24	7.93	14.7	17.2	12.7	13.4
	4	7.58	7.38	10.1	10.3	17.0	19.0	16.7	17.7
	8	3.86	3.65	5.45	5.79	12.1	11.5	6.89	9.17*
	8 Lab	5.17	6.76	7.52	7.93	16.5	15.4	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after six years

APPENDIX 6

TABLE 7

Mean Flexural Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Benzoyl Peroxide Cured Low Reactivity Polyester Resin

Site	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth		Woven Roving	
	Initial Flexural Modulus	6.62	8.00	7.45	8.48	13.8	21.7	9.93	16.1
	C of V	10.00	8.68	13.89	6.08	4.94	8.20	20.43	3.47
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)								
Temp	2	6.76	7.86	7.03	9.10	17.4	18.8	13.7	16.5
	4	6.48	7.58	7.58	8.20	18.0	19.4	12.1	13.5
	8	5.65	5.45	6.14	6.27	17.7	15.0	10.0	11.6*
	8 Lab	6.34	6.96	8.00	8.41	17.3	18.1	11.2	8.00*
Hot Dry	2	6.69	8.34	7.58	9.24	17.7	20.2	8.69	12.8
	4	7.65	8.34	7.65	8.34	17.2	18.5	6.76	14.6
	8	6.00	6.14	5.93	6.83	13.7	14.5	9.65	7.65*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	5.79	6.48	7.79	8.55	16.2	18.2	11.2	13.0
	4	9.79	11.4	10.4	11.9	21.0	23.8	10.6	11.0
	8	4.62	4.62	6.07	6.55	12.9	13.2	9.72	10.7
	8 Lab	6.96	7.58	7.17	8.20	16.5	17.5	-	-

TABLE 8

Mean Flexural Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Methyl Ethyl Ketone Peroxide Cured Low Reactivity Resin

Site	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth		Woven Roving	
	Initial Flexural Modulus	6.62	8.41	7.86	8.34	21.0	22.0	14.3	15.7
	C of V	13.2	9.20	12.3	7.77	13.66	3.13	2.36	5.69
	Conditions	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)								
Temp	2	5.65	6.69	7.03	8.14	19.5	19.8	15.9	15.9
	4	5.79	7.31	7.10	8.41	17.7	19.6	15.3	16.1
	8	5.86	5.72	6.27	6.69	15.1	15.0	9.72	9.31*
	8 Lab	5.93	6.55	6.41	6.96	16.8	17.5	12.0	12.4*
Hot Dry	2	6.48	7.31	7.38	8.34	16.6	19.3	13.7	14.3
	4	6.07	6.89	6.83	6.96	16.1	17.7	6.89	14.6
	8	5.10	6.00	6.27	6.41	13.3	14.7	9.17	10.6*
	8 Lab	-	-	-	-	-	-	-	-
Hot Wet	2	6.21	6.96	7.65	7.93	15.5	18.7	15.4	15.6
	4	8.55	9.72	9.79	11.2	19.4	22.1	15.0	15.2
	8	4.83	4.62	5.10	6.96	12.8	13.0	11.0	9.45*
	8 Lab	5.93	6.69	6.89	7.38	17.0	17.2	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after six years

TABLE 9

Mean Tensile Strength in MPa,
Glass Content in Percent and Acetone Soluble Matter in Percent after 2,4,6 and 8 Years Exposure
of all Laminates made with Benzoyl Peroxide Cured High Reactivity Resin

Site	Reinforcement	"A" Glass CSM			"E" Glass CSM			Satin Weave Cloth			Woven Roving		
		Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength
	Initial Property	27.6	8.4	68.3	31.6	8.2	111	57.3	6.8	270	48.6	6.2	231
	C of V			7.81			4.09			2.51			3.53
Site	Exposure (Years)												
Temp	2	27.6	8.0	56.5	30.1	7.5	93.8	59.0	6.7	268	50.8	6.5	250
	4	28.8	7.8	51.4	28.0	8.4	75.2	56.6	6.8	245	50.1	6.3	215
	8	32.3	9.9	41.5	36.3	8.8	77.4	54.6	7.3	196	51.9	5.9	220*
	8 Lab	35.7	12.2	65.1	35.7	9.5	109	60.3	8.2	289	49.5	6.6	249*
Hot Dry	2	28.0	7.7	51.0	32.3	6.3	108	57.5	6.3	240	53.2	5.9	241*
	4	-	-	59.3	-	-	78.1	-	-	212	-	-	198
	8	33.5	8.8	53.7	30.5	7.8	80.3	61.0	8.4	183	53.0	7.0	162*
	8 Lab	-	-	-	-	-	-	-	-	-	-	-	-
Hot Wet	2	31.9	7.1	50.9	34.6	6.7	76.8	58.3	7.2	205	52.2	5.8	205
	4	-	-	45.8	-	-	47.1	-	-	195	-	-	165
	8	34.3	10.5	31.0	33.2	9.1	52.6	59.8	9.6	113	49.8	8.0	231*
	8 Lab	35.1	10.8	64.7	35.8	10.5	98.9	64.7	7.8	223	-	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after six years

TABLE 10

Mean Tensile Strength in MPa.

Glass Content in Percent and Acetone Soluble Matter in Percent after 2,4,6 and 8 Years Exposure

of all Laminates made with Methyl Ethyl Ketone Peroxide Cured High Reactivity Polyester Resin

Site	Reinforcement	"A" Glass CSM			"E" Glass CSM			Satin Weave Cloth			Woven Roving		
		Glass	Acetone	Tensile Strength (55.2)	Glass	Acetone	Tensile Strength (86.3)	Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength
	Initial Property	24.8	7.6	43.0ƒ	30.8	7.6	68.2ƒ	56.2	4.0	282	48.0	7.0	222
	C of V			19.1			11.7			4.39			2.84
Site	Exposure (Years)												
Temp	2	28.5	8.1	58.9	26.1	7.4	77.2	58.0	6.7	274	49.2	7.2	245
	4	26.0	6.4	45.1	35.3	6.5	62.5	56.1	7.3	270	51.0	7.0	274
	8	30.9	9.5	48.7	24.4	12.3	75.5	58.8	7.4	250	48.6	6.6	203*
	8 Lab	39.2	8.9	46.3	25.9	8.5	86.0	58.5	7.6	240	49.1	6.8	284*
Hot Dry	2	26.2	6.4	55.2	27.3	6.4	86.3	53.8	5.9	228	53.0	6.3	303
	4	-	-	44.1	-	-	62.1	-	-	263	-	-	266
	8	26.2	7.9	43.2	27.3	6.6	81.0	59.7	7.7	218	51.5	6.7	221*
	8 Lab	-	-	-	-	-	-	-	-	-	-	-	-
Hot Wet	2	27.0	6.3	53.1	25.5	6.2	65.0	54.3	5.8	255	52.5	5.8	203
	4	-	-	44.9	-	-	56.7	-	-	211	-	-	184
	8	27.0	9.3	37.2	26.8	8.2	67.2	60.2	9.2	202	56.3	10.4	112
	8 Lab	21.8	10.7	61.1	26.6	9.9	67.9	57.5	9.2	252	-	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after six years

ƒ: Anomalous results. Two year Hot/Dry exposure figures used for initial TS.

TABLE 11

Mean Tensile Strength in MPa,
Glass Content in Percent and Acetone Soluble Matter in Percent after 2,4,6 and 8 Years Exposure
of all Laminates made with Benzoyl Peroxide Cured Low Reactivity Polyester Resin

Site	Reinforcement	"A" Glass CSM			"E" Glass CSM			Satin Weave Cloth			Woven Roving		
		Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength
	Initial Property	32.9	9.6	62.4	32.8	10.2	108	57.8	8.7	293	53.8	13.3	259
	C of V			8.22			4.34			2.36			3.59
Site	Exposure (Years)												
Temp	2	28.7	9.5	56.5	29.7	9.6	95.0	56.9	9.4	272	58.6	13.1	245
	4	34.0	8.7	49.3	36.6	9.7	85.7	58.6	8.4	277	43.2	13.4	238
	8	33.7	19.9	54.1	31.3	10.2	83.7	58.9	10.4	261	54.8	11.4	188*
	8 Lab	35.2	8.5	64.5	29.8	8.8	94.0	59.9	9.0	297	55.5	15.2	285*
Hot Dry	2	33.0	8.6	59.8	33.2	8.9	103	58.0	8.5	281	52.7	11.8	199
	4	-	-	59.3	-	-	88.7	-	-	230	-	-	173
	8	33.3	11.8	50.8	32.0	10.1	83.5	59.4	10.1	235	56.9	12.0	169*
	8 Lab	-	-	-	-	-	-	-	-	-	-	-	-
Hot Wet	2	32.5	8.2	57.4	28.9	8.4	116	59.4	8.3	301	52.6	9.5	226
	4	-	-	51.1	-	-	87.4	-	-	232	-	-	119
	8	33.2	9.7	40.8	29.8	12.0	79.6	60.1	9.6	180	50.7	10.2	237*
	8 Lab	32.3	14.4	61.6	31.9	12.6	99.4	58.5	9.7	290	-	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage
*: Woven roving final withdrawal after six years

TABLE 12

Mean Tensile Strength in MPa,
Glass Content in Percent and Acetone Soluble Matter in Percent after 2,4,6 and 8 Years Exposure
of all Laminates made with Methyl Ethyl Ketone Peroxide Cured Low Reactivity Polyester Resin

	Reinforcement	"A" Glass CSM			"E" Glass CSM			Satin Weave Cloth			Woven Roving		
		Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength	Glass	Acetone	Tensile Strength
	Initial Property	30.0	11.2	56.6	26.3	11.6	85.5	58.6	9.8	290	48.8	10.3	283
	C of V			5.81			4.77			4.14			2.35
Site	Exposure (Years)												
Temp	2	24.5	10.0	55.2	25.5	10.7	84.1	57.6	9.4	300	50.6	10.3	265
	4	24.3	10.0	45.6	27.6	10.0	67.9	57.4	9.7	302	50.0	10.1	303
	8	26.2	12.3	52.6	28.2	12.4	78.6	61.2	9.9	276	50.8	10.0	250*
	8 Lab	25.0	12.2	53.5	27.8	11.8	80.6	60.4	8.8	304	50.0	10.2	260*
Hot Dry	2	29.1	9.6	59.2	27.9	10.4	68.2	60.1	9.5	324	51.1	9.9	283
	4	-	-	52.9	-	-	45.6	-	-	283	-	-	231
	8	29.6	13.3	48.8	28.9	12.2	63.1	60.2	10.9	231	51.5	10.9	245*
	8 Lab	-	-	-	-	-	-	-	-	-	-	-	-
Hot Wet	2	31.4	9.5	44.6	30.9	11.0	71.2	59.0	7.5	289	50.7	9.8	265
	4	-	-	62.9	-	-	42.3	-	-	240	-	-	206
	8	26.3	11.1	42.6	[illegible]	11.2	69.3	59.0	11.3	218	53.6	7.0	141*
	8 Lab	25.4	11.6	56.7	26.8	11.5	84.4	58.7	10.9	309	-	-	-

NOTE: C of V: Coefficient of variation expressed as a percentage
*: Woven roving final withdrawal after six years

TABLE 13

Mean Tensile Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Benzoyl Peroxide Cured High Reactivity Polyester Resin

Site	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth	Woven Roving
	Initial Tensile Modulus	6.55	7.72	18.4	13.2
	C of V	5.87	3.37	3.53	3.77
	Exposure (Years)				
Temp	2	8.55	8.34	18.2	14.4
	4	8.55	8.41	18.0	15.5
	8	6.34	8.62	17.3	15.5*
	8 Lab	8.55	10.4	18.6	15.4*
Hot Dry	2	8.62	9.79	18.7	15.2
	4	8.89	9.65	19.8	15.1
	8	7.10	7.93	19.2	14.6*
	8 Lab	-	-	-	-
Hot Wet	2	7.24	8.20	17.6	14.8
	4	8.76	7.58	18.7	15.7
	8	5.93	6.41	17.2	16.1*
	8 Lab	8.14	7.93	19.4	-

TABLE 14

Mean Tensile Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Methyl Ethyl Ketone Peroxide Cured High Reactivity Polyester Resin

Site	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth	Woven Roving
	Initial Tensile Modulus	7.24	7.31	21.6	14.0
	C of V	3.78	4.76	2.25	4.14
	Exposure (Years)				
Temp	2	7.17	7.17	20.5	16.5
	4	6.69	7.65	19.8	17.1
	8	6.48	7.45	19.4	15.9*
	8 Lab	7.52	7.17	21.4	16.4*
Hot Dry	2	7.93	8.83	20.5	16.9
	4	7.38	8.20	22.6	17.3
	8	6.89	8.14	20.6	17.5*
	8 Lab	-	-	-	-
Hot Wet	2	7.24	7.86	19.1	15.7
	4	7.52	7.79	18.6	16.4
	8	5.65	8.14	20.3	15.0*
	8 Lab	6.75	8.20	21.5	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after six years

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TABLE 15

Mean Tensile Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Benzoyl Peroxide Cured Low Reactivity Polyester Resin

	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth	Woven Roving
	Initial Tensile Modulus	8.34	8.20	20.8	13.0
	C of V	4.88	1.56	2.20	2.73
Site	Exposure (Years)				
Temp	2	7.31	8.89	20.0	15.4
	4	7.86	10.1	19.6	16.9
	8	8.00	8.62	21.4	16.2*
	8 Lab	8.62	9.17	21.6	15.9*
Hot Dry	2	8.69	9.17	22.3	15.0
	4	9.72	9.79	22.2	16.3
	8	8.20	8.76	21.0	15.5*
	8 Lab	-	-	-	-
Hot Wet	2	8.07	9.72	21.9	15.0
	4	10.1	10.5	19.2	15.9
	8	7.58	9.10	20.5	17.2*
	8 Lab	8.41	8.69	22.9	-

TABLE 16

Mean Tensile Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Methyl Ethyl Ketone Peroxide Cured Low Reactivity Polyester Resin

	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth	Woven Roving
	Initial Tensile Modulus	7.31	8.55	21.6	13.7
	C of V	3.23	4.35	2.11	4.07
Site	Exposure (Years)				
Temp	2	6.34	7.45	20.1	14.0
	4	5.93	7.10	20.0	18.1
	8	6.48	7.93	21.6	15.0*
	8 Lab	7.58	7.65	21.8	16.7*
Hot Dry	2	7.79	8.69	21.4	15.7
	4	8.20	7.58	19.6	17.1
	8	6.76	7.45	19.9	16.8*
	8 Lab	-	-	-	-
Hot Wet	2	6.27	7.17	21.2	15.0
	4	7.65	6.00	19.0	15.0
	8	5.93	7.65	20.8	15.9*
	8 Lab	7.65	7.72	21.6	-

NOTE: C of V: Coefficient of variation expressed as a percentage

*: Woven roving final withdrawal after six years

TABLE 17

Mean Flexural Strength in MPa after 2,4,6 and 8 Years Exposure of all Laminates made with Epoxy Resin and Satin Weave Glass Cloth

	Curing Agent	MNA		DDM		TETA	
	Initial Flexural Strength	434		456		423	
	C of V	7.9		10.9		12.2	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)						
Temp	2	420	436	443	449	439	447
	4	337	391	377	434	437	481
	8	383	390	342	351	404	425
	8 Lab	463	472	446	464	438	453
Hot Dry	2	468	490	388	410	405	438
	4	456	454	408	401	367	344
	8	-	359	435	442	333	335
	8 Lab	-	-	-	-	-	-
Hot Wet	2	441	473	506	516	397	419
	4	398	425	385	354	332	359
	8	350	354	323	322	280	275
	8 Lab	456	494	497	500	461	498

TABLE 18

Mean Flexural Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Epoxy Resin and Satin Weave Glass Cloth

	Curing Agent	MNA		DDM		TETA	
	Initial Flexural Modulus	21.0		21.4		19.7	
	C of V	4.82		17.45		5.66	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry
Site	Exposure (Years)						
Temp	2	20.8	21.4	20.5	20.9	18.4	18.8
	4	18.8	20.3	19.3	19.9	17.9	17.8
	8	14.9	15.0	14.8	13.6	16.1	14.6
	8 Lab	17.7	17.9	18.3	19.3	15.1	15.7
Hot Dry	2	18.5	19.2	17.5	18.8	17.7	18.8
	4	18.3	19.3	18.5	18.5	17.0	17.9
	8	-	13.2	16.0	15.0	12.3	12.0
	8 Lab	-	-	-	-	-	-
Hot Wet	2	17.1	18.5	18.3	18.7	16.5	18.0
	4	11.9	11.7	11.2	11.7	11.2	11.6
	8	12.5	13.0	13.4	12.1	13.4	12.5
	8 Lab	16.1	16.8	18.1	17.7	17.1	16.5

NOTE: MNA: Methyl "Nadic" Anhydride

DDM: Diamino Diphenyl Methane

TETA: Triethylene Tetramine

APPENDIX 6

TABLE 19

Mean Tensile Strength in MPa after 2,4,6 and 8 Years Exposure of all Laminates made with Epoxy Resin and Satin Weave Glass Cloth

Site	Curing Agent	MNA	DDM	TETA
	Initial Tensile Strength	250	268	275
	C of V	6.41	5.24	2.64
Site	Exposure (Years)			
Temp	2	281	284	291
	4	248	250	301
	8	276	239	285
	8 Lab	256	289	285
Hot Dry	2	310	260	309
	4	282	282	237
	8	258	302	248
	8 Lab	-	-	-
Hot Wet	2	315	276	261
	4	276	236	219
	8	246	251	184
	8 Lab	296	307	306

TABLE 20

Mean Tensile Modulus in GPa after 2,4,6 and 8 Years Exposure of all Laminates made with Epoxy Resin and Satin Weave Glass Cloth

Site	Curing Agent	MNA	DDM	TETA
	Initial Tensile Modulus	22.3	22.2	19.0
	C of V	3.17	1.94	3.35
Site	Exposure (Years)			
Temp	2	21.9	22.1	20.4
	4	21.1	23.1	20.3
	8	22.2	21.3	21.2
	8 Lab	24.6	22.5	20.5
Hot Dry	2	21.5	21.1	22.4
	4	22.4	20.1	19.5
	8	20.0	20.2	16.8
	8 Lab	-	-	-
Hot Wet	2	21.4	23.0	20.7
	4	21.9	22.1	21.1
	8	19.9	20.0	19.9
	8 Lab	22.5	22.0	19.9

NOTE: MNA: Methyl "Nadic" Anhydride

DDM: Diamino Diphenyl Methane

TETA: Triethylene Tetramine

TABLE 1

Mean Flexural Strength in MPa and Loss of Flexural Strength Percent for all Laminates made with HR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth	
	Initial Flexural Strength MEKP Cure	134		195		365	
	Initial Flexural Strength BP Cure	114		192		347	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry
Temp	MEKP Cure	108	121	153	169	279	354
	Loss Percent	19.6	9.7	21.4	13.6	23.4	2.7
	BP Cure	73.2	83.8	106	130	175	217
	Loss Percent	35.6	26.4	44.9	32.2	49.6	37.3
Hot Dry	MEKP Cure	106	112	152	179	248	277.0
	Loss Percent	21.2	16.5	22.2	8.1	32.1	24.0
	BP Cure	80.3	97.9	93.7	134	164	214
	Loss Percent	29.4	14.0	51.3	30.2	52.6	38.2
Hot Wet	MEKP Cure	74.1	77.5	133	139	202	249
	Loss Percent	44.9	42.4	32.0	28.7	44.5	31.6
	BP Cure	54.6	64.7	59.9	74.4	118	163
	Loss Percent	52.0	43.1	68.9	61.3	66.0	51.4

TABLE 2

Mean Flexural Strength in MPa and Loss of Flexural Strength Percent for all Laminates made with LR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth	
	Initial Flexural Strength MEKP Cure	149		208		369	
	Initial Flexural Strength BP Cure	141		221		413	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry
Temp	MEKP Cure	111	124	146	171	268	324
	Loss Percent	25.2	16.6	29.9	18.0	27.4	12.1
	BP Cure	97.2	104	166	187	261	322
	Loss Percent	30.9	25.9	25.0	15.4	36.9	22.1
Hot Dry	MEKP Cure	107	124	164	169	251	280
	Loss Percent	28.3	16.6	21.3	18.6	31.9	23.9
	BP Cure	91.4	99.6	121	147	231	274
	Loss Percent	35.0	29.2	45.5	33.6	44.1	33.8
Hot Wet	MEKP Cure	81.4	87.9	136	136	225	262
	Loss Percent	45.4	41.0	34.7	34.7	38.9	29.1
	BP Cure	71.2	71.2	131	141	207	232
	Loss Percent	49.4	49.4	41.0	36.3	49.8	43.9

APPENDIX 7

TABLE 3

Mean Flexural Modulus in GPa and Loss of Flexural Modulus Percent for all Laminates made with HR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth	
	Initial Flexural Modulus MEKP Cure	7.58	Dry Conditioned	9.93	Dry Conditioned	21.4	Dry Conditioned
	Initial Flexural Modulus BP Cure	6.83		10.1		19.2	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry
Temp	MEKP Cure	5.52	5.72	6.14	6.48	13.5	13.4
	Loss Percent	27.3	24.5	38.2	34.7	36.8	37.1
	BP Cure	4.76	4.83	5.45	5.93	12.1	12.3
	Loss Percent	30.3	29.3	45.9	41.1	37.1	35.6
Hot Dry	MEKP Cure	4.96	5.38	6.14	6.96	13.1	13.2
	Loss Percent	34.5	29.1	38.2	29.9	38.7	38.1
	BP Cure	4.69	5.10	4.62	5.45	12.8	13.3
	Loss Percent	31.3	25.3	54.1	45.9	33.5	31.0
Hot Wet	MEKP Cure	3.86	3.65	5.45	5.79	12.1	11.5
	Loss Percent	49.1	51.8	45.1	41.7	43.6	46.1
	BP Cure	3.24	3.59	3.38	3.86	11.1	11.7
	Loss Percent	52.5	47.5	66.4	61.6	42.1	39.2

TABLE 4

Mean Flexural Modulus in GPa and Loss of Flexural Modulus Percent for all Laminates made with LR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM		"E" Glass CSM		Satin Weave Cloth	
	Initial Flexural Modulus MEKP Cure	8.41	Dry Conditioned	8.34	Dry Conditioned	22.0	Dry Conditioned
	Initial Flexural Modulus BP Cure	8.00		8.48		21.7	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry
Temp	MEKP Cure	5.86	5.72	6.27	6.69	15.1	15.0
	Loss Percent	30.3	32.0	24.8	19.8	31.4	31.7
	BP Cure	5.65	5.45	6.14	6.27	17.7	15.0
	Loss Percent	29.3	31.9	27.6	26.0	18.7	31.1
Hot Dry	MEKP Cure	5.10	6.00	6.27	6.41	13.3	14.7
	Loss Percent	39.3	28.7	24.8	23.1	39.5	33.2
	BP Cure	6.00	6.14	5.93	6.83	13.7	14.5
	Loss Percent	25.0	23.3	30.1	19.5	37.1	33.3
Hot Wet	MEKP Cure	4.83	4.62	5.10	6.96	12.8	13.0
	Loss Percent	42.6	45.1	38.8	16.5	42.0	40.8
	BP Cure	4.62	4.62	6.07	6.55	12.9	13.2
	Loss Percent	42.2	42.2	28.5	22.8	40.6	39.4

TABLE 5

Mean Tensile Strength in MPa and Loss of Tensile Strength Percent for all Laminates made with HR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth
	Initial Tensile Strength MEKP Cure	55.2*	86.3*	282
	Initial Tensile Strength BP Cure	68.3	111	270
Temp	MEKP Cure	48.7	75.5	250
	Loss Percent	11.7	12.5	11.3
	BP Cure	41.5	77.4	196
	Loss Percent	39.1	30.1	27.4
Hot Dry	MEKP Cure	43.2	81.0	218
	Loss Percent	21.7	6.1	22.7
	BP Cure	53.7	80.3	183
	Loss Percent	21.4	27.4	32.4
Hot Wet	MEKP Cure	37.2	67.2	202
	Loss Percent	32.5	22.2	28.3
	BP Cure	31.0	52.6	113
	Loss Percent	54.6	52.5	58.3

* Initial results anomalous, 2 year hot/dry used instead.

TABLE 6

Mean Tensile Strength in MPa and Loss of Tensile Strength Percent for all Laminates made with LR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth
	Initial Tensile Strength MEKP Cure	56.6	85.5	290
	Initial Tensile Strength BP Cure	62.4	108	293
Temp	MEKP Cure	52.6	78.6	276
	Loss Percent	7.07	8.08	4.77
	BP Cure	54.1	83.7	261
	Loss Percent	13.3	22.2	11.1
Hot Dry	MEKP Cure	48.8	63.1	231
	Loss Percent	13.8	26.2	20.4
	BP Cure	50.8	83.5	235
	Loss Percent	18.5	22.4	20.0
Hot Wet	MEKP Cure	42.6	69.3	218
	Loss Percent	24.7	18.9	24.7
	BP Cure	40.8	79.6	180
	Loss Percent	34.6	26.0	38.6

APPENDIX 7

TABLE 7

Mean Tensile Modulus in GPa and Gain or Loss of Tensile Modulus Percent for Laminates made with HR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth
	Initial Tensile Modulus MEKP Cure	7.24	7.31	21.6
	Initial Tensile Modulus BP Cure	6.55	7.72	18.4
Temp	MEKP Cure	6.48	7.45	19.4
	Loss/Gain Percent	-10.5	+1.92	-10.2
	BP Cure	6.34	8.62	17.3
	Loss/Gain Percent	-3.21	+11.7	-5.98
Hot Dry	MEKP Cure	6.89	8.14	20.6
	Loss/Gain Percent	-4.83	+11.4	-4.63
	BP Cure	7.10	7.93	19.2
	Loss/Gain Percent	+8.40	+2.72	-4.35
Hot Wet	MEKP Cure	5.65	8.14	20.3
	Loss/Gain Percent	-22.0	+11.4	-6.48
	BP Cure	5.93	6.41	17.2
	Loss/Gain Percent	-9.47	-17.0	-6.52

TABLE 8

Mean Tensile Modulus in GPa and Gain or Loss of Tensile Modulus Percent for Laminates made with LR Polyester Resin Cured with Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide after 8 Years Exposure

After 8 Years	Reinforcement	"A" Glass CSM	"E" Glass CSM	Satin Weave Cloth
	Initial Tensile Modulus MEKP Cure	7.31	8.55	21.6
	Initial Tensile Modulus BP Cure	8.34	8.20	20.8
Temp	MEKP Cure	6.48	7.93	21.7
	Loss/Gain Percent	-11.4	-7.25	0
	BP Cure	8.00	8.62	21.4
	Loss/Gain Percent	-4.08	+5.12	+2.40
Hot Dry	MEKP Cure	6.76	7.45	19.9
	Loss/Gain Percent	-7.52	-12.9	-7.87
	BP Cure	8.20	8.76	21.0
	Loss/Gain Percent	-1.68	+6.83	+1.00
Hot Wet	MEKP Cure	5.93	7.65	20.8
	Loss/Gain Percent	-18.9	-10.5	-4.17
	BP Cure	7.58	9.10	20.5
	Loss/Gain Percent	-9.11	+11.0	-1.92

TABLE 9

Mean Flexural Strength in MPa and Modulus in GPa and Change Percent in these Properties after 8 Years Exposure for all Laminates made with Epoxy Resin and Satin Weave Glass Cloth

After 8 Years	Curing Agent	MNA		DDM		TETA	
	Initial Flexural Strength	434		456		423	
	Conditioning	Wet	Dry	Wet	Dry	Wet	Dry
Temp	Flexural Strength	383	390	342	351	404	425
	Loss Percent	11.7	10.2	25.2	23.1	4.3	0
Hot Dry	Flexural Strength	-	359	435	442	333	335
	Loss Percent	-	17.3	4.6	3.2	21.1	20.6
Hot Wet	Flexural Strength	350	354	323	322	280	275
	Loss Percent	19.3	18.5	29.1	29.5	33.8	34.9
	Initial Flexural Modulus	21.0		21.4		19.7	
Temp	Flexural Modulus	14.9	15.0	14.8	13.6	16.1	14.6
	Loss Percent	29.2	28.5	30.9	36.2	18.5	25.9
Hot Dry	Flexural Modulus	-	13.2	16.0	15.0	12.3	12.0
	Loss Percent	-	37.4	25.4	30.2	37.4	39.2
Hot Wet	Flexural Modulus	12.5	13.0	13.4	12.1	13.4	12.5
	Loss Percent	40.7	38.0	37.3	43.7	31.8	36.7

TABLE 10

Mean Tensile Strength in MPa and Modulus in GPa and Change Percent in these Properties after 8 Years Exposure for all Laminates made with Epoxy Resin and Satin Weave Glass Cloth

After 8 Years	Curing Agent	MNA	DDM	TETA
	Initial Tensile Strength	250	268	275
Temp	Tensile Strength	276	239	285
	Loss/Gain Percent	+10.4	-10.8	+3.5
Hot Dry	Tensile Strength	258	302	248
	Loss/Gain Percent	+3.0	+12.9	-9.8
Hot Wet	Tensile Strength	246	251	184
	Loss/Gain Percent	-1.6	-6.0	-33.1
	Initial Tensile Modulus	22.3	22.2	19.0
Temp	Tensile Modulus	22.2	21.3	21.2
	Loss/Gain Percent	-0.45	-4.05	+11.6
Hot Dry	Tensile Modulus	20.0	20.2	16.8
	Loss/Gain Percent	-10.3	-9.01	-11.6
Hot Wet	Tensile Modulus	19.9	20.0	19.9
	Loss/Gain Percent	-10.8	-9.91	+4.74

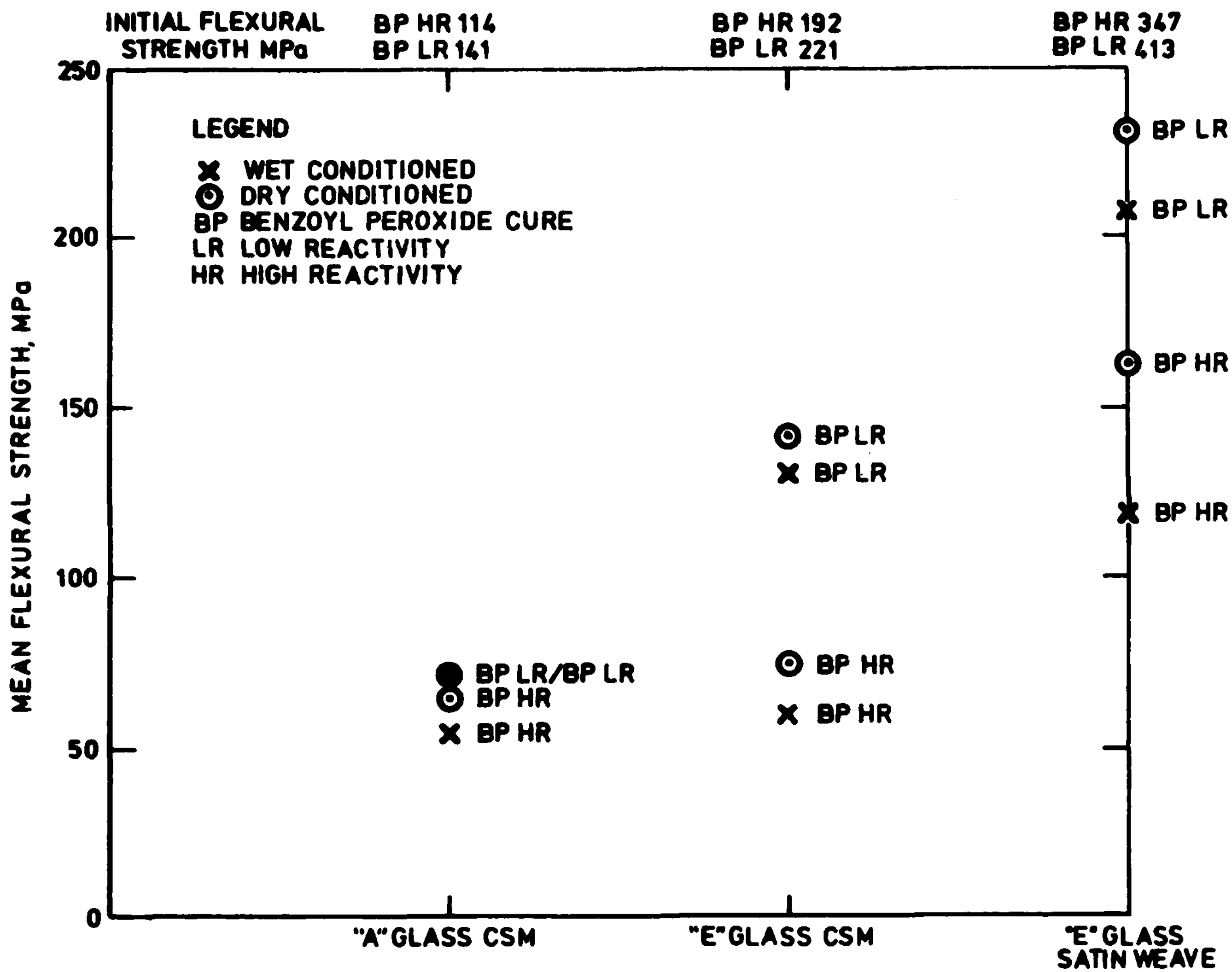

FIG. 8.1 MEAN FLEXURAL STRENGTH AFTER 8 YEARS HOT/WET EXPOSURE OF LAMINATES MADE WITH "A" AND "E" GLASS REINFORCEMENT AND BENZOYL PEROXIDE CURED HIGH AND LOW REACTIVITY POLYESTER RESIN.

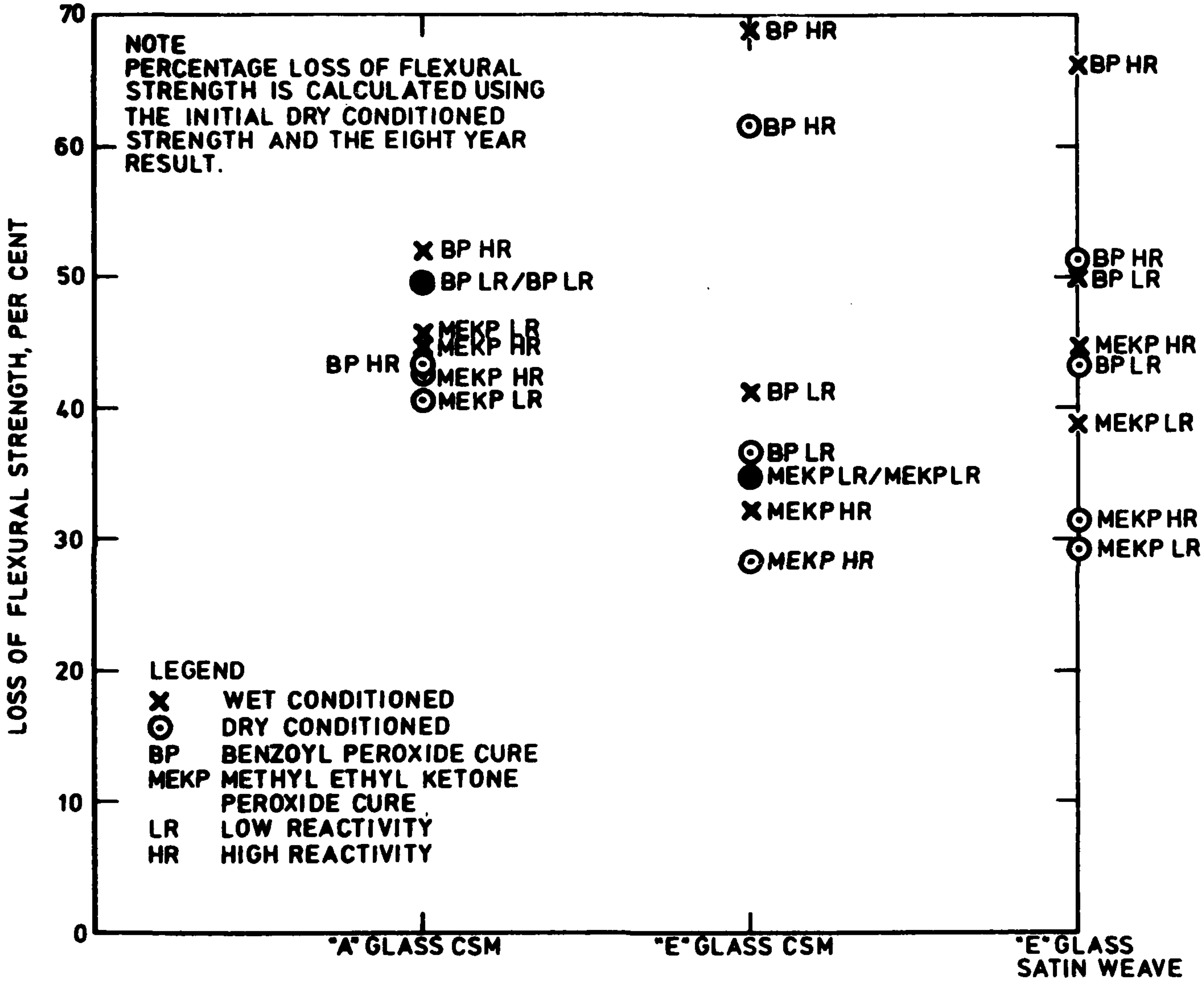

FIG. 8.2 PERCENTAGE LOSS OF FLEXURAL STRENGTH AFTER 8 YEARS HOT/WET EXPOSURE FOR LAMINATES MADE WITH "A" AND "E" GLASS REINFORCEMENT AND MEK PEROXIDE AND BENZOYL PEROXIDE CURED HIGH AND LOW REACTIVITY POLYESTER RESIN.

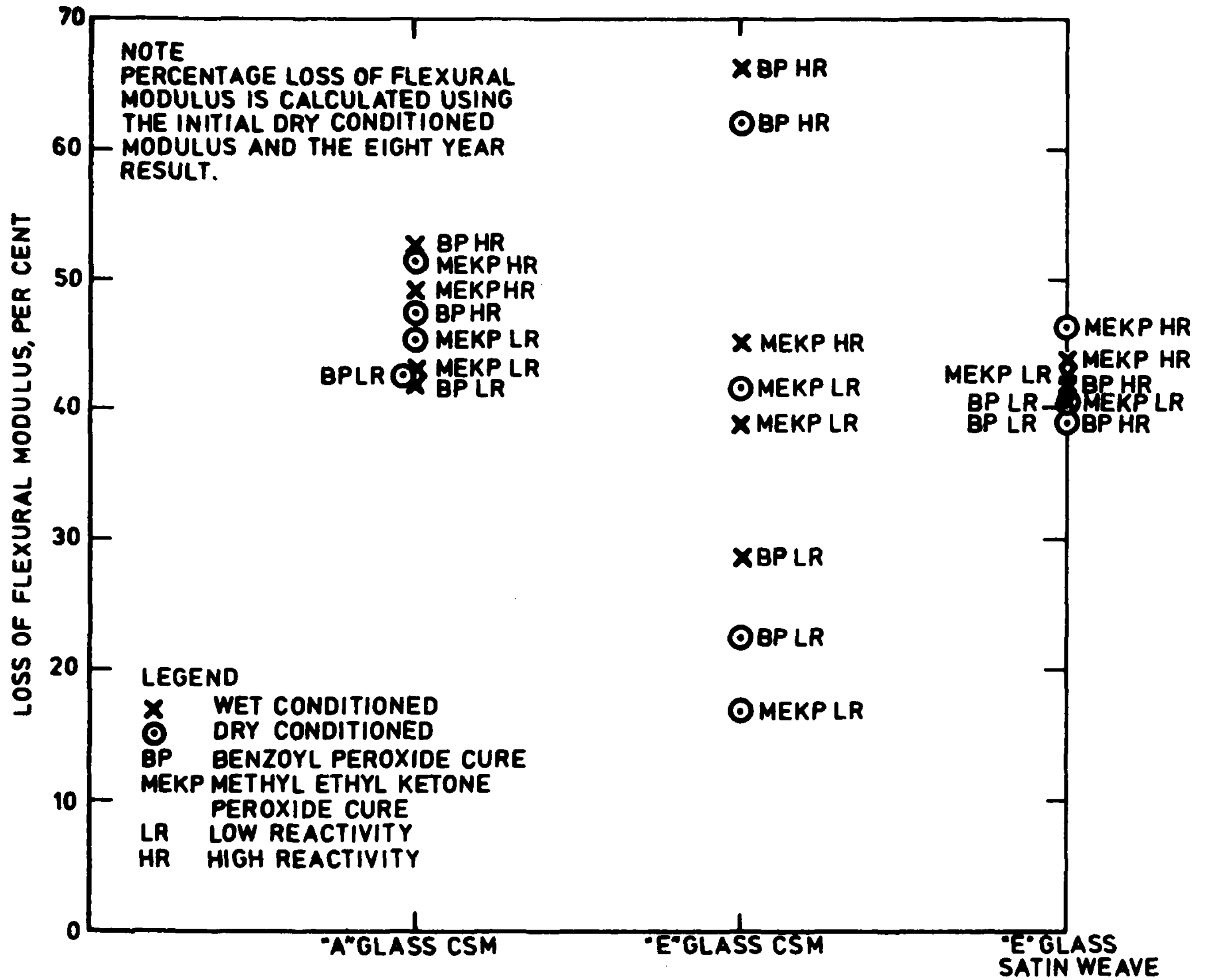

FIG. 8.3 PERCENTAGE LOSS OF FLEXURAL MODULUS AFTER 8 YEARS HOT/WET EXPOSURE FOR LAMINATES MADE WITH "A" AND "E" GLASS REINFORCEMENT AND MEK PEROXIDE AND BENZOYL PEROXIDE CURED HIGH AND LOW REACTIVITY POLYESTER RESIN.

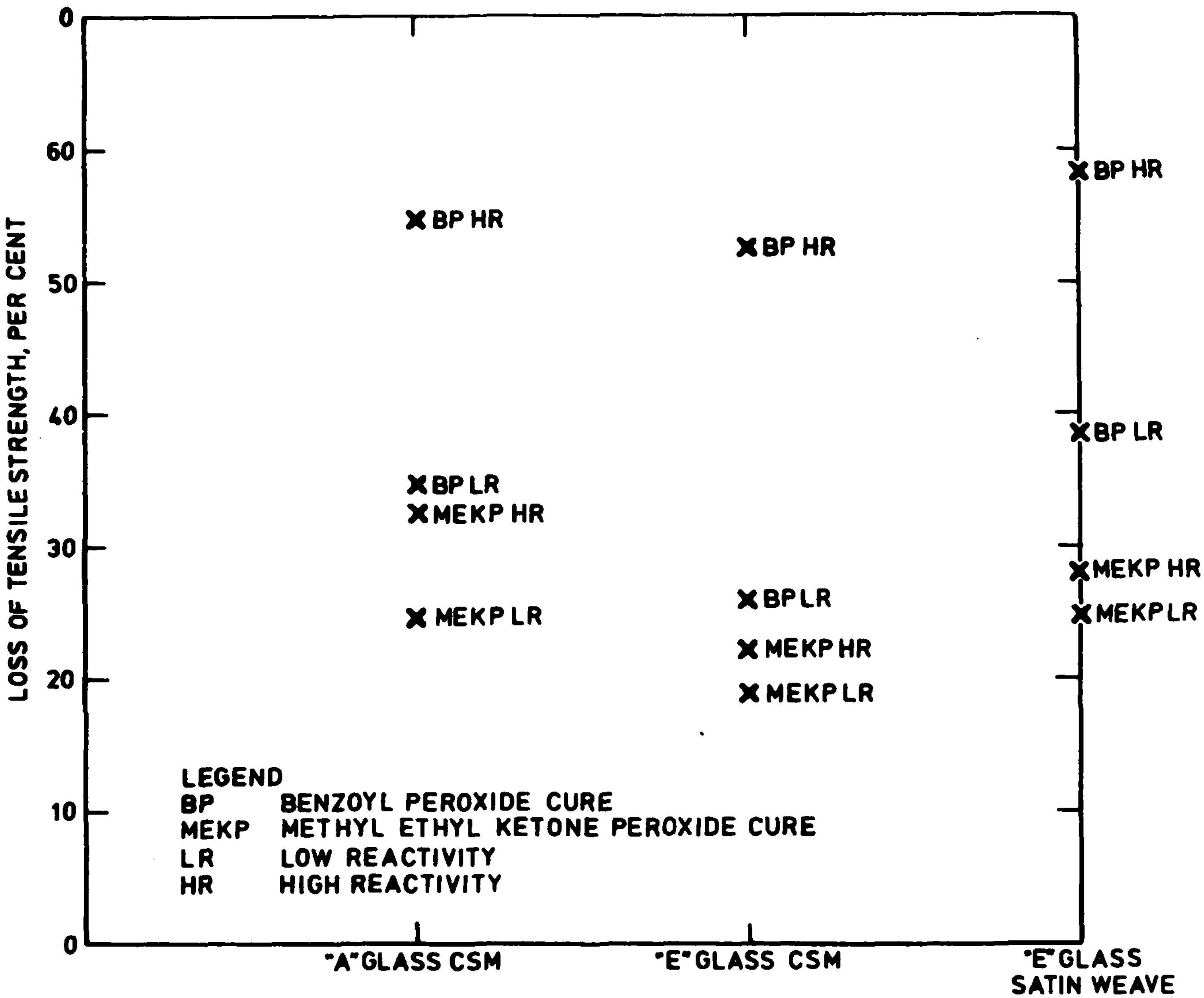

FIG. 8.4 PERCENTAGE LOSS OF TENSILE STRENGTH AFTER 8 YEARS HOT/WET EXPOSURE FOR LAMINATES MADE WITH "A" AND "E" GLASS REINFORCEMENT AND MEK PEROXIDE AND BENZOYL PEROXIDE CURED HIGH AND LOW REACTIVITY POLYESTER RESIN.

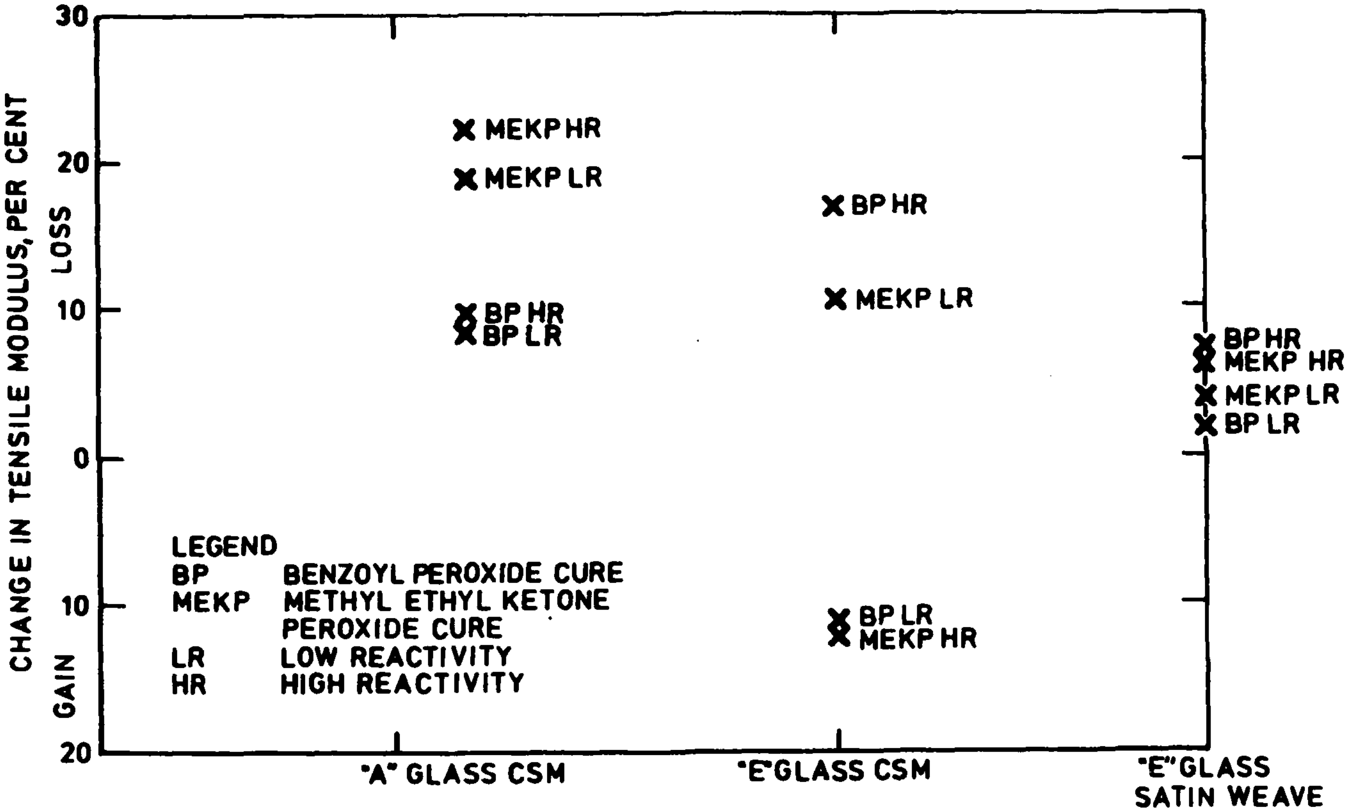

FIG. 8.5 PERCENTAGE CHANGE IN TENSILE MODULUS AFTER 8 YEARS HOT/WET EXPOSURE FOR LAMINATES MADE WITH "A" AND "E" GLASS REINFORCEMENT AND MEK PEROXIDE AND BENZOYL PEROXIDE CURED HIGH AND LOW REACTIVITY RESINS

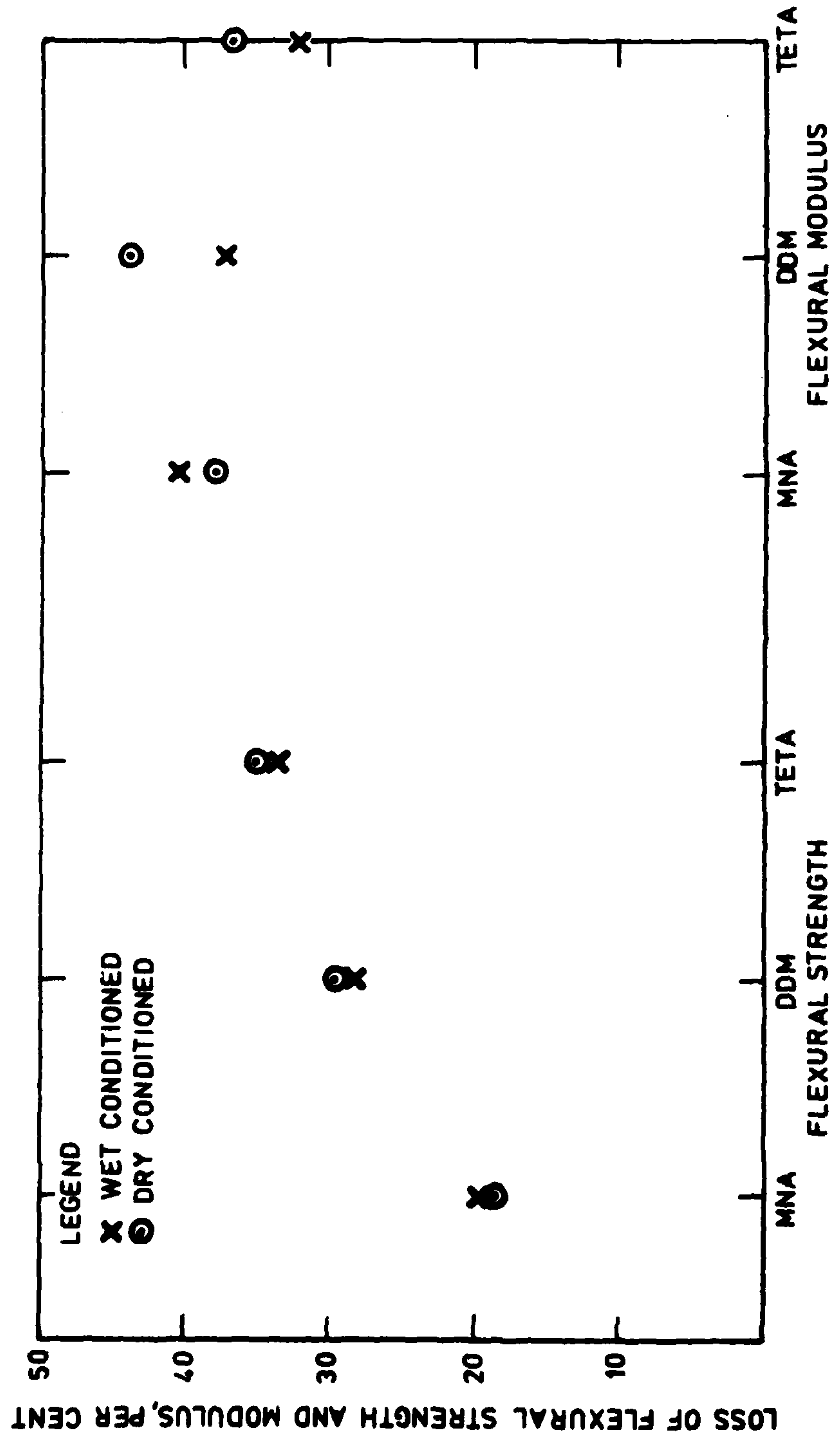

FIG. 8.6 PERCENTAGE LOSS OF FLEXURAL STRENGTH AND MODULUS AFTER 8 YEARS HOT/WET EXPOSURE FOR LAMINATES MADE WITH "E" GLASS REINFORCEMENT AND EPOXY RESIN CURED WITH VARIOUS AGENTS.

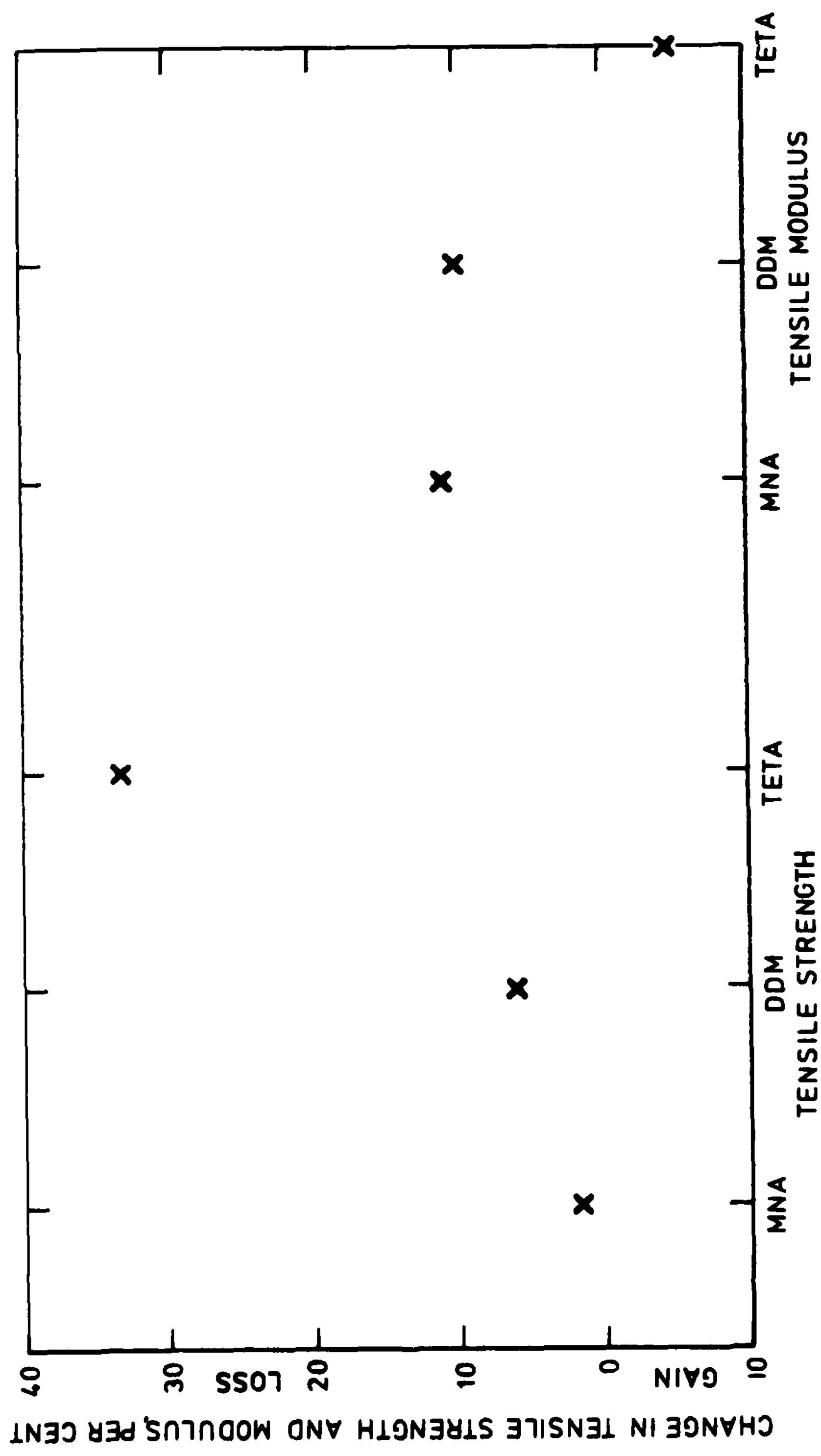

FIG. 8.7 CHANGE IN TENSILE STRENGTH AND MODULUS AFTER 8 YEARS HOT/WET EXPOSURE OF LAMINATES MADE WITH "E" GLASS REINFORCEMENT AND EPOXY RESIN CURED WITH VARIOUS AGENTS.

DETAILED LIST OF MECHANICAL PROPERTY CONCLUSIONS

A9.1 Degradation of Mechanical Properties of Laminates made with Polyester Resin

The conlusions relating to the degradation of mechanical properties are based on an analysis of results for initial flexural strength and modulus and initial tensile strength and modulus, and results for the same properties determined after 8 years exposure on the three sites.

1. The flexural strength of all laminates had fallen after 8 years exposure at the temperate, hot/dry and hot/wet sites.

2. Deterioration was greatest on the hot/wet site where the flexural strength loss, covering all reinforcements, was in the range 30-69 percent of initial values. The flexural strength loss range for the hot/dry site was 8-53 percent and that for the temperate site 10-50 percent.

3. Apart from one or two isolated figures, laminate flexural strength measured in the dry conditioned state was found to be greater than that after wet conditioning, irrespective of resin reactivity, cure, environment and exposure time.

4. Laminates made with benzoyl peroxide cured resin, low or high reactivity, sustained, on the whole, a greater percentage loss of flexural strength after exposure for 8 years at any of the three sites than the corresponding laminates prepared from MEK peroxides cured high or low reactivity resin.

5. Laminates made with low reactivity polyester resin, benzoyl peroxide or MEK peroxide cured, had higher initial flexural strengths than their high reactivity counterparts. This superiority was maintained up to and including the 8 year exposure period at all three sites.

6. In general, the laminates which showed the least degradation in flexural strength after 8 years exposure at the hot/wet site were those made with MEK peroxide cured low reactivity polyester resin. Even so, the loss of flexural strength was in the range 30-45 percent of initial strength values.

7. With one exception, "E" glass CSM laminates made with benzoyl peroxide or MEK peroxide cured high reactivity resin, the initial dry conditioned flexural modulus values were very similar for laminates made with benzoyl peroxide or MEK peroxide cured high or low reactivity resin.

8. For all cases but one, "E" glass CSM laminates made with benzoyl peroxide cured low reactivity resin the results for which appear to be anomalous, the greatest flexural modulus losses were recorded for material exposed for 8 years at the hot/wet site and these ranged from 17-66 percent of the initial figures obtained from dry conditioned material. The range of flexural modulus loss for the temperate and hot/dry sites was 19-46 percent and 20-54 percent respectively.

9. The broad conclusion can be drawn that the lowest flexural modulus losses after 8 years hot/wet exposure were recorded for laminates made with MEK peroxide or benzoyl peroxide cured low reactivity resin.

10. With only three exceptions, out of 16 different resin reactivity, cure and reinforcement combinations, the greatest flexural modulus losses after 8 years exposure at any of the sites were recorded for laminates made with benzoyl peroxide cured high reactivity resin.

11. In all cases and at all three sites the tensile strength of material had fallen after the 8 year exposure period.

12. The greatest degradation in tensile strength occurred at the hot/wet site and property loss for this environment was in the range 19-58 percent. The range for tensile strength loss for the temperate and hot/dry sites was 5-39 percent and 6-32 percent respectively.

13. Invariably, the greatest tensile strength losses were recorded for laminates made with benzoyl peroxide cured high reactivity resin, range 22-58 percent.

14. Almost without exception the lowest tensile strength losses were derived from laminates made with low reactivity resin, range 5-39 percent.

15. There is a very clear indication from the results of the tensile strength tests, and from the flexural strength tests, that MEK peroxide curing whether used to make laminates with high or low reactivity resin, is beneficial if laminates are to have the greatest resistance to environmental exposure.

16. Tensile modulus losses after 8 years exposure on any of the sites were not large and in many cases there was in fact an apparent small modulus gain not related to resin reactivity, type of cure or exposure site. The range of tensile modulus loss, or gain, after 8 years exposure was -22 percent to +12 percent.

17. Property losses for laminates exposed at the hot/dry site were usually bracketed by those from laminates at the temperate and hot/wet sites. Thus, in any future weathering trials of laminates made with polyester resins, consideration should be given to limiting the scale of the trial at hot/dry sites and even to omitting this exposure environment altogether.

18. Considering all laminate types, the tensile strength and modulus losses ranged up to 58 percent of initial values after 8 years hot/wet exposure. Such losses are serious and will inevitably adversely affect the size of design and safety factors.

A9.2 Degradation of Mechanical Properties of Laminates made with Epoxy Resin

Only a very limited range of glass/epoxy resin laminates was used in the trial and, unlike the results from the polyester resin laminates, the results from these laminates do not show any very clear trends. However the following general observations can be made:

1. On the whole, the highest property losses were recorded for laminates which had been exposed for 8 years at the hot/wet site, but many of the results from the temperate and hot/dry sites were of the same order - particularly for flexural strength and modulus.

2. Flexural modulus losses, range 19-44 percent, were greater than flexural strength losses after 8 years exposure at any of the sites and indicated severe fibre/resin bond damage or damage to the reinforcement.

3. There was an almost total absence of any sign of recovery of flexural properties after drying out, tensile properties were not tested in both the wet and dry conditioned state. The lack of property recovery on drying out after severe environmental exposure has also been observed in previous work at RAE on the environmental behaviour of glass/epoxy resin laminates.

4. Tensile strength and modulus were little affected after 8 years exposure at all three sites. The one exception to this observation was the 33 percent loss of tensile strength after hot/wet exposure of laminates made with epoxy resin cured with triethylene-tetramine (TETA). This was the only cold cured resin/hardener system used.

5. From the limited amount of data available the indications are that, of the three resin/hardener system tested, the best all round resistance to the hot/wet environment was given by laminates made with resin cured with methyl nadic anhydride.

REPORT DOCUMENTATION PAGE

(Notes on completion overleaf)

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(TEST)

Abstract This report contains the results of a trial conducted in Australia and the United Kingdom to evaluate the weathering of glass fibre re-inforced laminates. The laminates represented a number of commercially available resin/glass combinations including polyester and epoxy resins, woven roving, chopped strand mat and satin weave glass reinforcement.

Some difficulty was experienced in interpreting the experimental results but positive trends are established for the long term, eight year behaviour. Some differentiation between resin systems has been possible.

END